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PROCUREMENT EXECUTIVE MINISTRY OF DEFENCE

TRIALS TO COMPARE THE STOPPING PERFORMANCE OF THREE ANTI SKID SYSTEMS AND TO DEMONSTRATE METHODS OF DETERMINING AIRCRAFT STOP DISTANCES ON THE STANDARD MILITARY REFERENCE WET SURFACE

I BEATY AND R W SUGG

ISSUED BY:
DEFENCE RESEARCH INFORMATION CENTRE
Station Square House, St. Mary Cray, Orpington, Kent, BR5 3RE

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TRIALS TO COMPARE THE STOPPING PERFORMANCE OF THREE (Determining) ANTI-SKID SYSTEMS AND TO DEMONSTRATE METHODS OF [redacted] AIRCRAFT STOP DISTANCES ON THE STANDARD MILITARY REFERENCE WET SURFACE

10   11 Oct 79

I. BEATY [redacted] R.W. SUGG
Mechanical Engineering Research and Development 1, St Giles Court, London.

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SUMMARY

The main part of this report is concerned with a trial to determine if there was any difference in the stop distance of a BAC 1-11 aircraft under wet runway conditions when fitted with three different modern anti-skid systems. The test runway was wetted by four water bowsers and the slipperyness of the surface at the time of the aircraft braked runs determined by a Mu-Meter friction trailer. A test with the Mu-Meter during a period of natural rain confirmed the similarity in runway friction between natural and bowser wetting methods.

By comparing the aircraft stop distances at the Mu-Meter reading of .6 it was concluded that although the two more modern systems appeared to give the shorter distance, the difference was small and based on insufficient data points to give a high degree of confidence.

The aircraft Braking Force Coefficient versus speed and Mu-Meter reading from one of the runs has been used to demonstrate the use of the method recommended in Ref 1 to determine the stop distance on the Standard Military Reference Wet Surface at the weight at which the aircraft was tested.

The Appendices contain a method of deciding on the suitability of a test runway for aircraft/Mu-Meter braking trials using National and NATO standards, recommendations on how to conduct the trials and how to determine Mu-Meter speed/friction curves for the test surface. A brief description is given of a trial on a runway with a large amount of standing water.

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DEFENCE RESEARCH INFORMATION CENTRE
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Kent BR5 3RE

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1. INTRODUCTION

1.1 The development of new and increasingly sophisticated anti skid systems are frequently accompanied by claims of reduced stop distances which are not based on operational aircraft trials. These systems may now be approaching such a high degree of efficiency that there may be little difference in their performance and the opportunity arose to investigate this point by conducting a joint trial with British Aerospace using a BAC 1-11 to compare the stop distances of the aircraft using three anti skid systems under controlled conditions. These trials also provided an opportunity to demonstrate the method of correcting stop distances to the Standard Military Reference Wet Surface as recommended in Ref 1.

1.2 The opportunity also arose to join in similar trials on a Hawk aircraft. These used the same basic test procedure as the BAC 1-11 and are described in Appendix G. The results presented a new problem in reducing the stop distance to the Standard since the deceleration/speed curve had to be used in lieu of friction coefficient/speed.

2. TEST AIRCRAFT

2.1 The aircraft was a BAC 1-11 G-ASYD in 670 configuration with Rolls Royce Spey Mk 512-14 DW engines plus hush kit. The brake units were the standard production 5 plate spider rotors and heat sinks equivalent to production standards. Standard production tyres were inflated to 80 psi for the MOD(PE) comparative trial and no tyre had less than 50% of its original groove depth left for the wet runs. The tread depths and pressures were measured before and after each run.

2.2 Aircraft deceleration was measured by an F47 camera situated at the side of the runway and a deviation camera at the runway end in line with the centre line. Wind speed, direction, ambient temperature and pressure were recorded at a convenient site near to and half way along the runway. Longitudinal deceleration, pitch angle, brake pressures, main wheel speeds, spoiler and lift dumper angles were also recorded.

3. CONTINUOUS RECORDING RUNWAY FRICTION METER (MU-METER)

3.1 As recommended in Ref 1, the Mu-Meter was used to measure the runway friction. The equipment which is described in Ref 2 is a trailer consisting of three wheels, two of which are mounted on independently moveable arms with a toe out angle of approximately 15°. When pulled the resulting side force imposed on the arms is sensed by a pressure capsule mounted between them and the pressure variations are transmitted to a pen recorder, this pressure being a measure of surface friction.

4. TEST SECTION

4.1 The Hurn 08/26 runway chosen for the trial is 6030ft long, 150ft wide, crowned and surfaced with asphalt. Before the trial started a standard Mu-Meter classification test was conducted in accordance with Annex B to NATO STANAG 3811 (see Appendix A) and Annex D to the National Air Traffic Service instruction to stations for procedure to be used for a full wet runway evaluation, see Appendix B. The results detailed in Appendix C show it to have a comparatively high friction surface with a Runway Friction Classification of 'acceptable'. However under natural rain and artificial wetting conditions the variation in friction in both longitudinal and transverse directions was considerable. One of the requirements for the trial was to have a test area with relatively constant but low friction. Preliminary Mu-Meter runs with bowser wetting indicated that the initial test section contained a high friction area; consequently it was re-positioned to a point starting 400ft from the western end of the runway and 30ft to the north of the centreline. This left 2000ft of the 6000ft runway as a safety margin. Even with this re-siting there was still a 750ft length of high friction surface in the test area. Five markers were placed approximately 900ft apart, see Fig 1, to serve as distance indicators.

5. RUNWAY TRIALS

5.1 The trials followed closely the standard method of test in Appendix D. The test section was wetted by four water bowsers, each capable of depositing 2500 gallons of water on to the runway through a 15ft spreader bar in 8 minutes.

5.2 Before each series of landings the runway was given a preliminary wetting followed by a further wetting immediately before each landing. Two bowsers started off from marker 1 in echelon just north of the runway centreline, heading in an easterly direction at 5 mph. At the same time the other two bowsers started off from the other end of the test strip at marker 5 again north of the centre line heading in a westerly direction. On the completion of the run, the bowsers were refilled and carried out a final wetting except that the pair of bowsers nearest to the centre line travelled in tandem.

5.3 The time of the start and finish of each wetting was recorded. Although all the water was deposited just north of the runway centre line, the slope on the northern side allowed the water to run down and wet the whole width of the test section.

5.4 Immediately the bowsers left the runway after the second wetting and before the aircraft landed, the Mu-Meter made one easterly run at 40 mph along the test section, 30ft to the north of the centre line, marking the trace as it passed each marker, see Fig 2. The exception to this procedure was when data was being collected to establish if there were any advantages in wetting the runway twice, when runs were also made after the first wetting. The results of this trial are in Appendix E.

5.5 When the Mu-Meter cleared the runway, the aircraft was landed on the test section and brought to a standstill for about 2 seconds. The only retardation devices used were spoilers, lift dumpers and brakes; reverse thrust was not used. The aircraft performance was measured by an F47 camera together with a Shackman deviation camera.

5.6 Immediately the aircraft cleared the runway, the Mu-Meter made a westerly run through the test section, see Fig 3, followed by four more passes. Each run was timed so that a graph of average Mu-Meter reading over the aircraft stop distance against time could be plotted. Knowing the time of the aircraft run the corresponding Mu-Meter reading was determined. See Fig 4.

5.7 Dry runway tests were also carried out on the same runway. However results from one anti skid system have not been included because of a brake malfunction. The results are shown in Table 1 and plotted in Fig 5 from which it can be seen that it was possible to achieve a runway slipperyness condition during the aircraft braked run which was within the Mu-Meter limits of $.55 \pm .05$ set by Ref 1 for correction to the Standard Military Reference Wet Curve.

6. CORRECTION OF AIRCRAFT BRAKING FORCE COEFFICIENT TO THE STANDARD MILITARY REFERENCE WET SURFACE

6.1 Ref 1 recommends that when it is required to specify a standard military wet surface it should be defined by a Mu-Meter reading at 40 mph of .55 and the following speed/friction equation.

$$\mu_V = .2 + 10^{\frac{V + 13}{-117}} \qquad \text{Equation 1}$$

where μ_V is the Mu-Meter reading at velocity V in mph. Provided the Mu-Meter reading at 40 mph is within $.55 \pm .05$, Ref 1 recommends a correction can be made to the aircraft speed/friction curve in proportion to the Mu-Meter readings. In these particular trials, aircraft run 54 has been chosen to give an example of how the correction is made. The Mu-Meter 40 mph reading for this run was .60 and using Fig 4 of Ref 1 gives a speed/friction curve with the equation

$$\mu_V = .23 + 10^{\frac{V + 26}{-153}} \qquad \text{Equation 2}$$

6.2 To check Equation 1 use was made of the alternative method described in para 3.4 of Ref 1. This trial is described in Appendix F and gives the equation

$$\mu_V = .23 + 10^{\frac{V + 30}{-167}} \qquad \text{Equation 3}$$

which is very similar to Equation 2 but probably more accurate.

6.3 Using Equation 3, the Mu-Meter speed/friction curve for aircraft run 54 is compared with the Standard Military Reference Wet Curve in Fig 6. The aircraft speed/friction curve for this run is corrected in Fig 7 to the Standard by the process described in Para 3.3 of Ref 1. The stop distance calculated from the corrected curve is that for the Standard Military Reference Wet Surface.

7. DISCUSSION

7.1 Runway Classification trials in accordance with Appendices A and B and reported in Part 2 of Appendix C show that with a constant water depth the friction level is comparatively constant throughout the runway length. Under natural rain conditions however (see Part 3 of Appendix C) the friction varies considerably and experience indicates this is due to the formation of ponds. A comparison of Figs C(3)-5 and 6 of Appendix C show the similarity in friction under natural and bowser wetted conditions. It would appear therefore that the friction variation under the aircraft test conditions is due to ponding and not necessarily to changes in micro and macrotexture.

7.2 Preliminary Mu-Meter runs were made in different tracks which showed that friction varied in the lateral as well as longitudinal direction and this was one of the factors which caused the test area to be moved to try and give more constant and lower friction conditions. Since the former objective was not fully achieved (see Figs 2 and 3) and the aircraft 'brakes on' point varied, the relationship between speed and runway friction was not always the same, consequently difference in aircraft stop distance might have occurred for the same Mu-Meter reading. Because the Mu-Meter reading is an average over the aircraft stop distance, this error should be small, but a runway with friction characteristics similar to Fig 8 would have simplified the data reduction. The narrowness of the test track, the fact that it was not possible to mark it clearly and the need to phase the runway occupancy time with normal airport activity made the trial relatively difficult to conduct.

7.3 Faulty brake operation occurred during the dry stops with anti skid system type 3 so the stop distances have been assumed to be the same as for types 1 and 2 since the brake will tend to be torque limited under dry conditions for some portion of the stop and therefore not greatly influenced by anti skid characteristics.

7.4 A comparison of stop distances from the same 'brakes on' speed in Fig 5 show that anti skid systems 1 and 3 appear to have a marginal advantage over system 2 down to a Mu-Meter reading of .6. However the differences are so small and the amount of data so limited that no great confidence should be placed on the result. There is certainly no dramatic difference between their wet runway capabilities and this is possibly due to the fact that modern systems operate close to their maximum efficiencies.

7.5 The aircraft braking force coefficient versus velocity plot for run 54 is shown in Fig 7. The sudden and large drop in runway friction opposite marker 4 gave low brake force values in the 70-80 knot region. These have been ignored since it has to be assumed the friction characteristics of the test runway are substantially the same along its length.

7.6 The aircraft speed/friction curve corrected to the Standard is shown in Fig 7 from which the stop distance can be calculated.

7.7 The 'alternative' method of determining the Mu-Meter speed/friction curve for the runway described in para 3.4 of Ref 1 has been used with success. The trial results are given in Appendix F.

7.8 The friction conditions for the Hawk trials (see Appendix G) were more variable than those at Hurn. This was due almost entirely to the presence of standing water and made determining the average Mu-Meter reading over the aircraft stop distance more difficult than usual. However it provided an opportunity of demonstrating how difficult conditions can be and how the aircraft stop distance can be corrected to that on the Standard surface when thrust, drag and lift are not known accurately. Using the method described in Appendix G the Hawk stop distance on the Military Standard Reference Wet Surface at 8800lb approx from 105 knots is 3240ft.

8. CONCLUSIONS

8.1 At an aircraft weight of approximately 78,000lb and with a 45° flap angle the BAC 1-11 with anti skid types 1 and 3 showed a marginal improvement over type 2 under wet conditions down to a Mu-Meter reading of .6.

8.2 Before deciding if a runway is suitable for trials of this type it is advisable to conduct a Runway Classification Trial in accordance with

NATO Stanag 3811 to decide if the surface can be made sufficiently slippery and that friction does not vary unduly along its length.

8.3 The method described in Ref 1 to reduce stop distances to a Standard Military Reference Wet Surface has been used successfully.

8.4 A method has been developed to correct stop distances to the Standard using deceleration in place of braking force coefficient.

8.5 Wetting a runway twice before the aircraft braked run does not appear to have any advantages over a single wetting.

9. RECOMMENDATIONS

9.1 When deciding on the suitability of a particular runway for testing anti skid systems or determining the stop distance on the Standard Military Reference Wet Surface, Mu-Meter runs should first be made in accordance with the 'low speed' method of NATO Stanag 3811 Annex B.

9.2 Preliminary bowser wetting trials should be conducted to determine the best pattern for the vehicles to adopt, also the Mu-Meter speed/friction curve should be established in accordance with Appendix F.

9.3 The Mu-Meter should be operated by experienced personnel.

9.4 In determining the relationship between aircraft stop distance and Mu-Meter reading at least 6 braked stops are needed at varying degrees of runway friction.

9.5 The method described in Appendix D be used to determine the relationship between Mu-Meter reading and aircraft stop distance.

9.6 Where insufficient aerodynamic data is available to determine aircraft braking force coefficient, the method described in Appendix G be used to determine the stop distance on the Standard Military Reference Wet Surface.

10. REFERENCES

1. R W Sugg A means of specifying a Standard Reference Wet Surface for military aircraft. S and T Memo 1/79.

2. R W Sugg An investigation into the use of measuring runway surface texture by the grease patch and Outflow Meter methods. S and T memo 2/79.

TABLE 1

BAC 1-11 TRIALS AT HURN

Run	Anti Skid Type	Runway Condition	Tyre Pressure	Flap Deg	Weight lbs	Corrected Stop Distance From 110KTS-FT	Average Mu-Meter Reading	Remarks
51	1	Dry	80 psi	45	80160	1080	.80	
52		Dry	"	45	78888	1150	.80	
53		Damp	"	45	78610	1585	.64	
54		Wet	"	45	79820	1849	.60	
55		Wet	"	45	76760	1766	.61	
56		Wet	"	20	84660	1977	.50	
57		Wet	"	20	82000	2212	.52	
58		Damp	"	45	78970	1454	.66	
59	2	Dry	80 psi	45	80900	1117	.80	
60		Dry	"	45	79600	1114	.80	
61		Wet	"	45	76800	1750	.64	
62		Wet	"	45	73700	1876	.61	
63		Wet	"	20	84200	1872	.66	
64		Wet	"	20	81980	1829	.64	
65		Dry	"	20	85250	1182	.80	
66		Dry	"	20	83050	1182	.80	
69	3	Wet	80 psi	45	77980	1774	.67	
70		Wet	"	45	75850	1705	.60	
71		Wet	"	20	83820	1791	.61	
72		Wet	"	20	81420	1872	.61	
75		Dry	"	20	85600	1250	.80	)
76		Dry	"	20	84530	1297	.80	) Long stop distance due
77		Dry	"	45	81700	1393	.80	) to brake malfunction

LAYOUT OF TEST AREA ON HURN RUNWAY

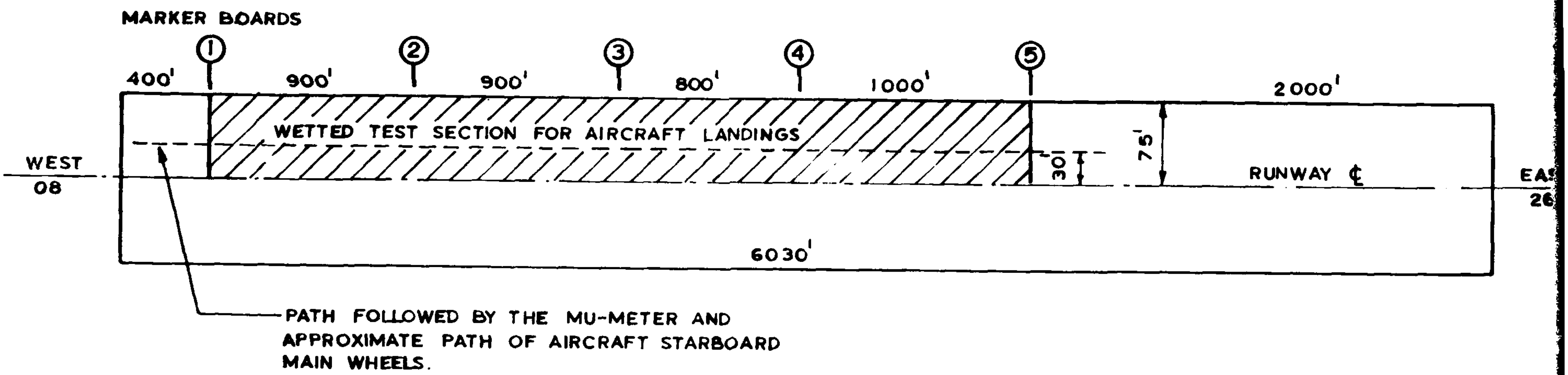


FIG. 1

MU-METER TRACE FOR HURN

PRIOR TO AIRCRAFT RUN 54

DRAWING NUMBER GM C 62920

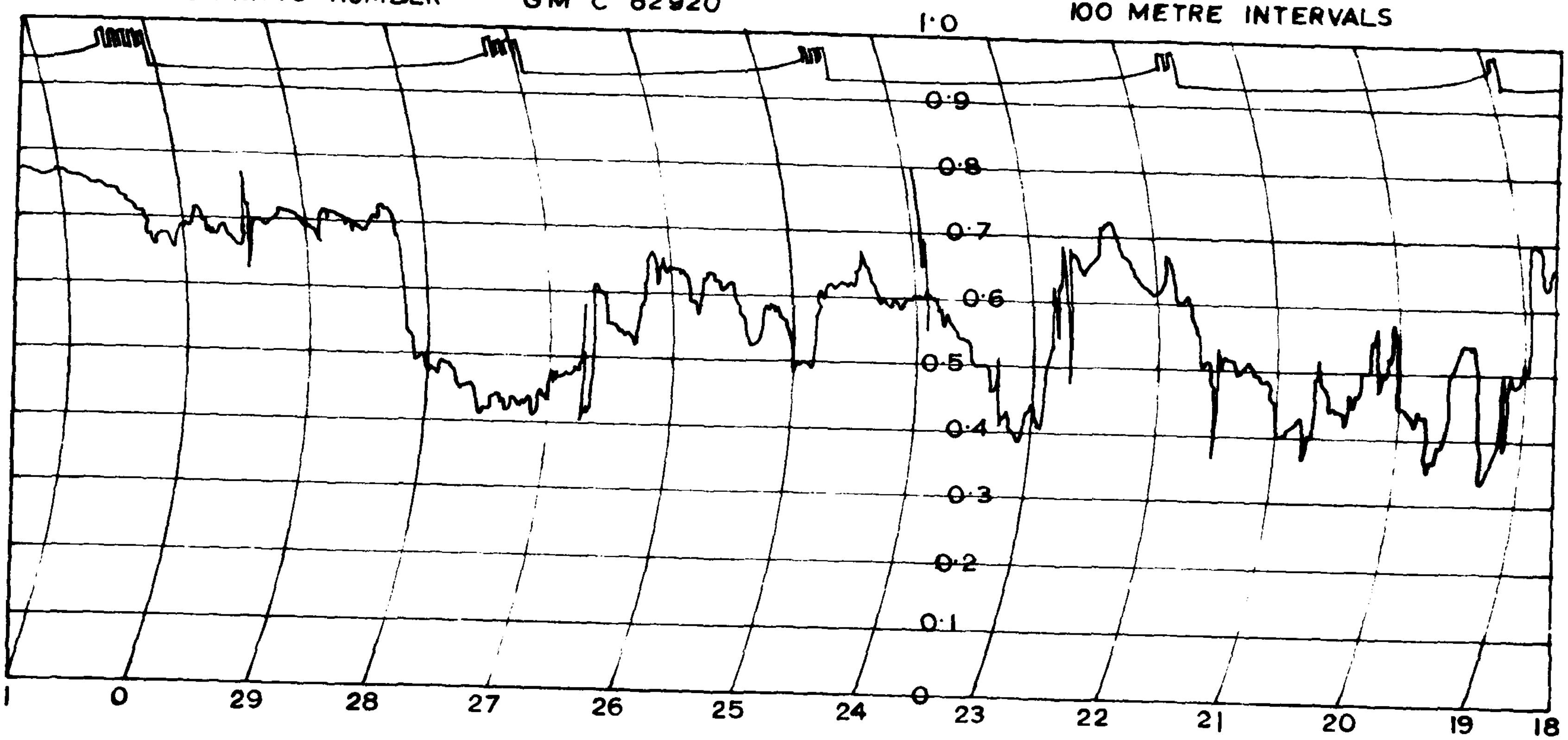


FIG. 2

MU-METER TRACE FOR HURN
POST AIRCRAFT RUN 54

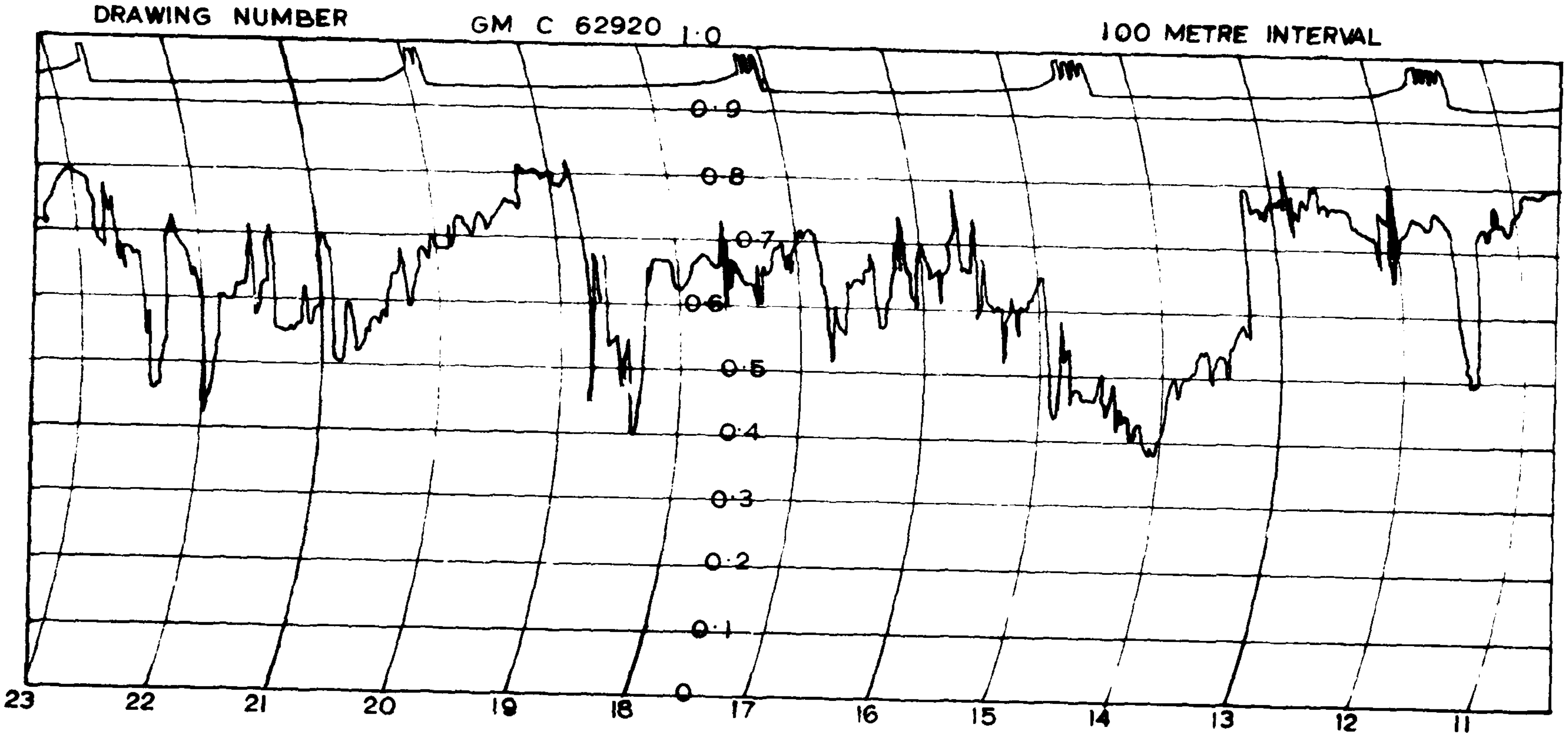
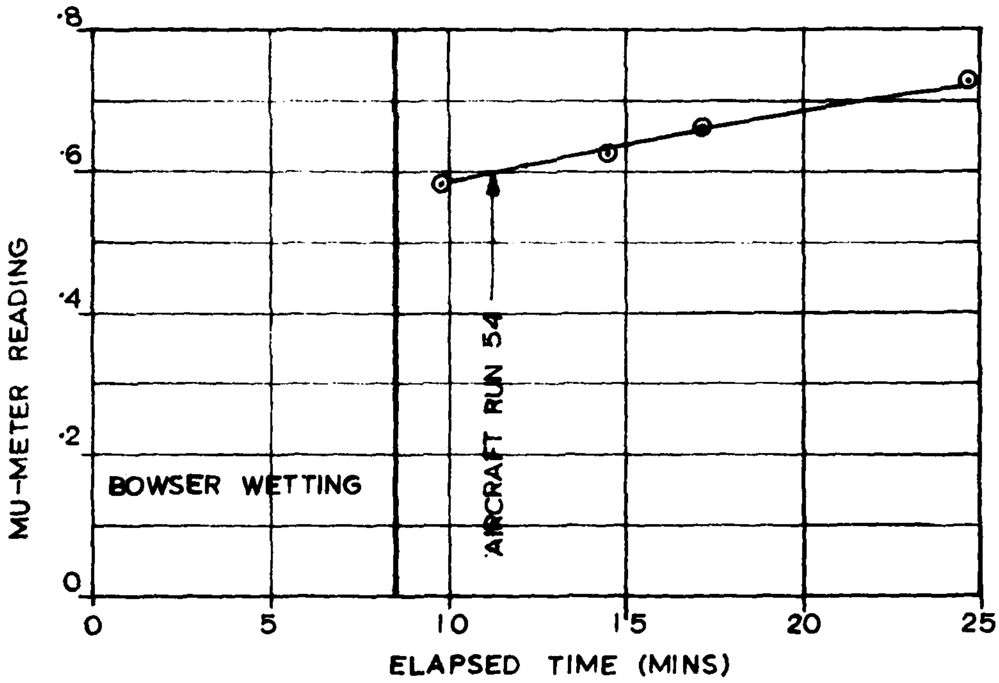


FIG. 3



MU-METER READING VERSUS TIME FOR AIRCRAFT RUN 54

FIG. 4

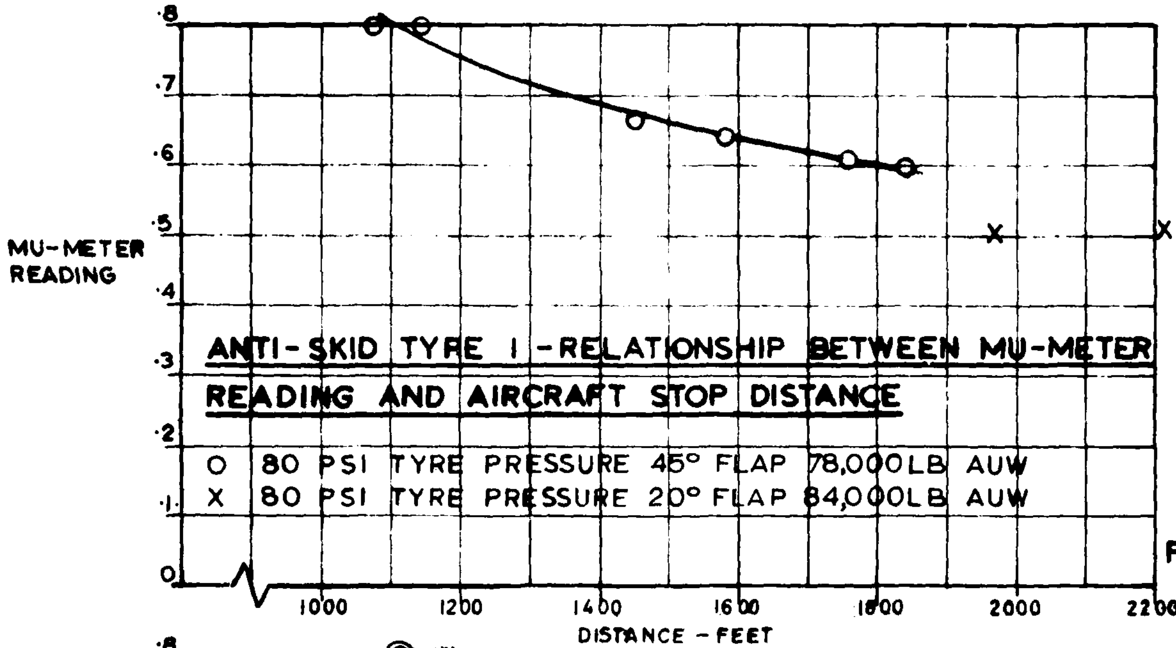


FIG.5A

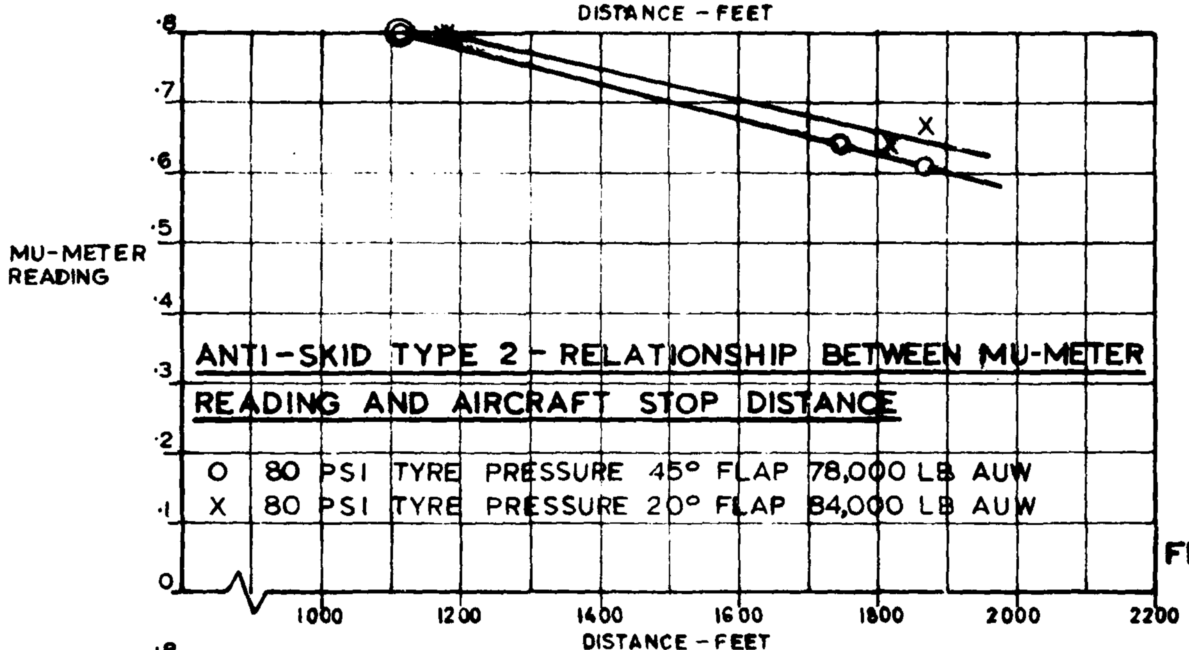


FIG.5B

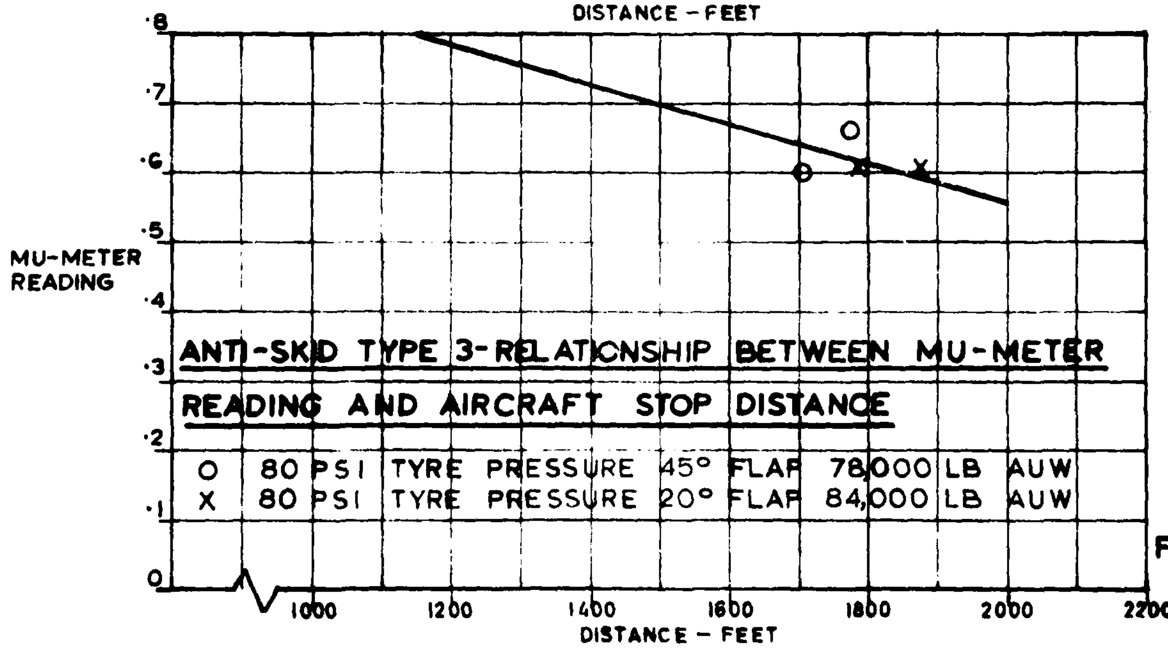


FIG.5C

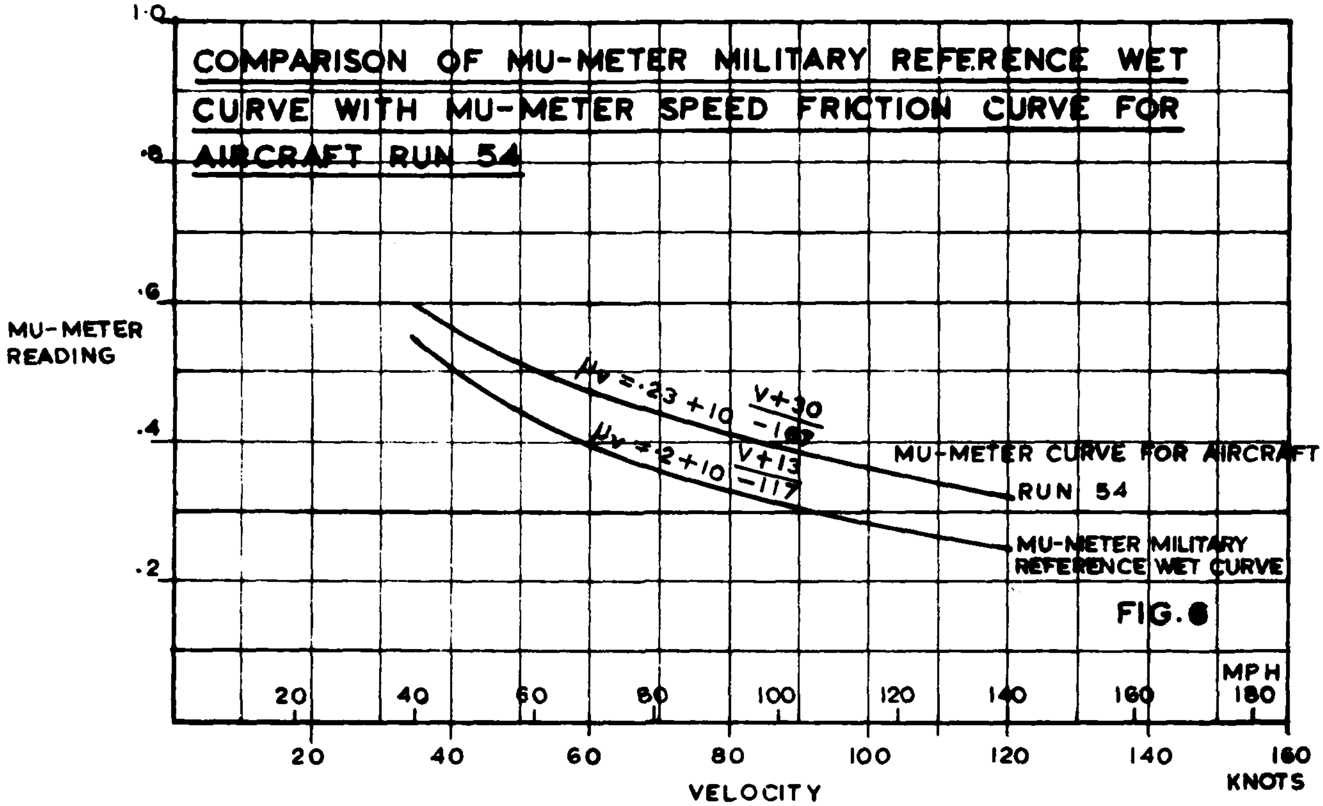

COMPARISON OF MU-METER MILITARY REFERENCE WET CURVE WITH MU-METER SPEED FRICTION CURVE FOR AIRCRAFT RUN 54
MU-METER READING
1·0
·8
·6
·4
·2
μv = ·23 + 10 (V+30)/(−167)
μv = ·2 + 10 (V+13)/(−117)
MU-METER CURVE FOR AIRCRAFT RUN 54
MU-METER MILITARY REFERENCE WET CURVE
MPH
20 40 60 80 100 120 140 160 180
20 40 60 80 100 120 140 160
KNOTS
VELOCITY

FIG. 6

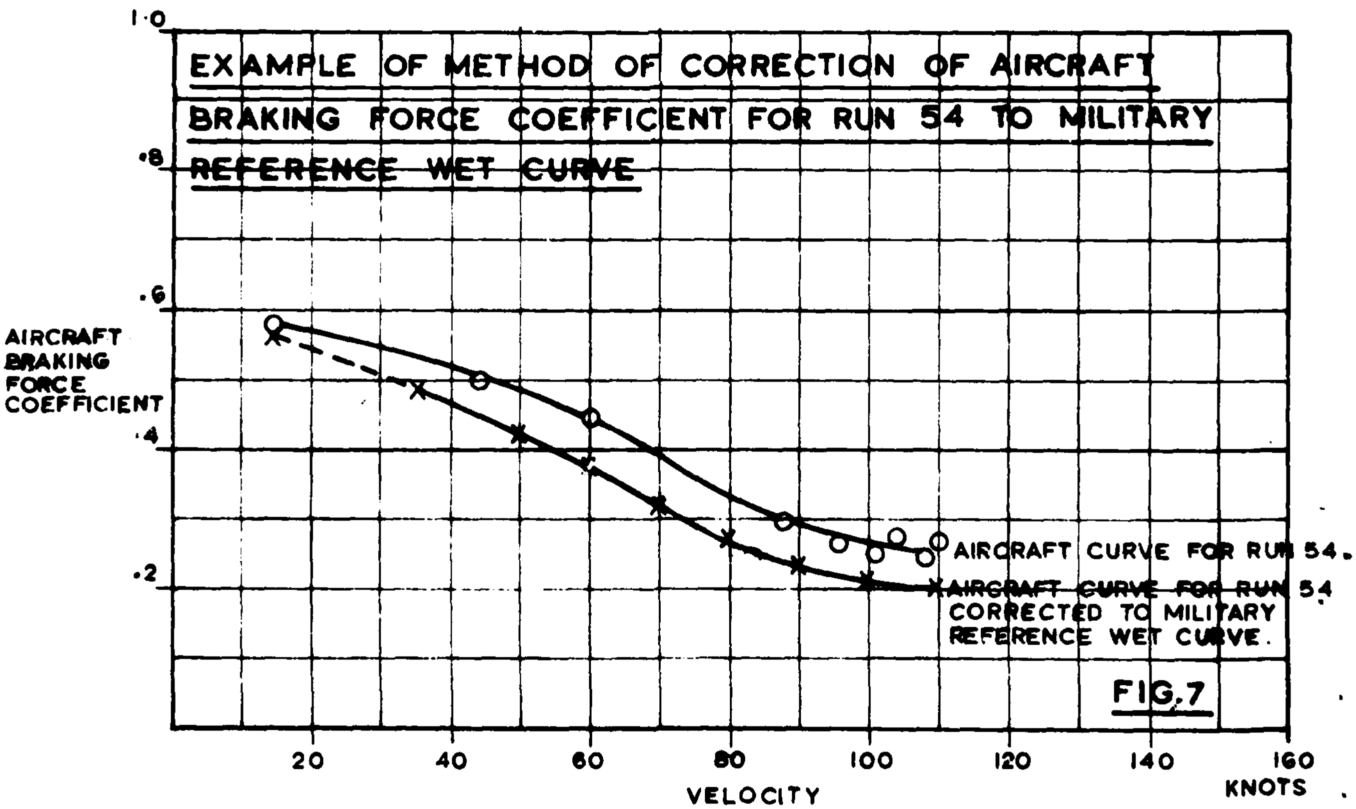

EXAMPLE OF METHOD OF CORRECTION OF AIRCRAFT BRAKING FORCE COEFFICIENT FOR RUN 54 TO MILITARY REFERENCE WET CURVE
AIRCRAFT BRAKING FORCE COEFFICIENT
1·0
·8
·6
·4
·2
AIRCRAFT CURVE FOR RUN 54.
AIRCRAFT CURVE FOR RUN 54 CORRECTED TO MILITARY REFERENCE WET CURVE.
20 40 60 80 100 120 140 160
KNOTS
VELOCITY

FIG. 7

MU-METER TRACE FOR LUBBOCK TEXAS

IMMEDIATELY AFTER BOWSER WETTING - CONCRETE SURFACE

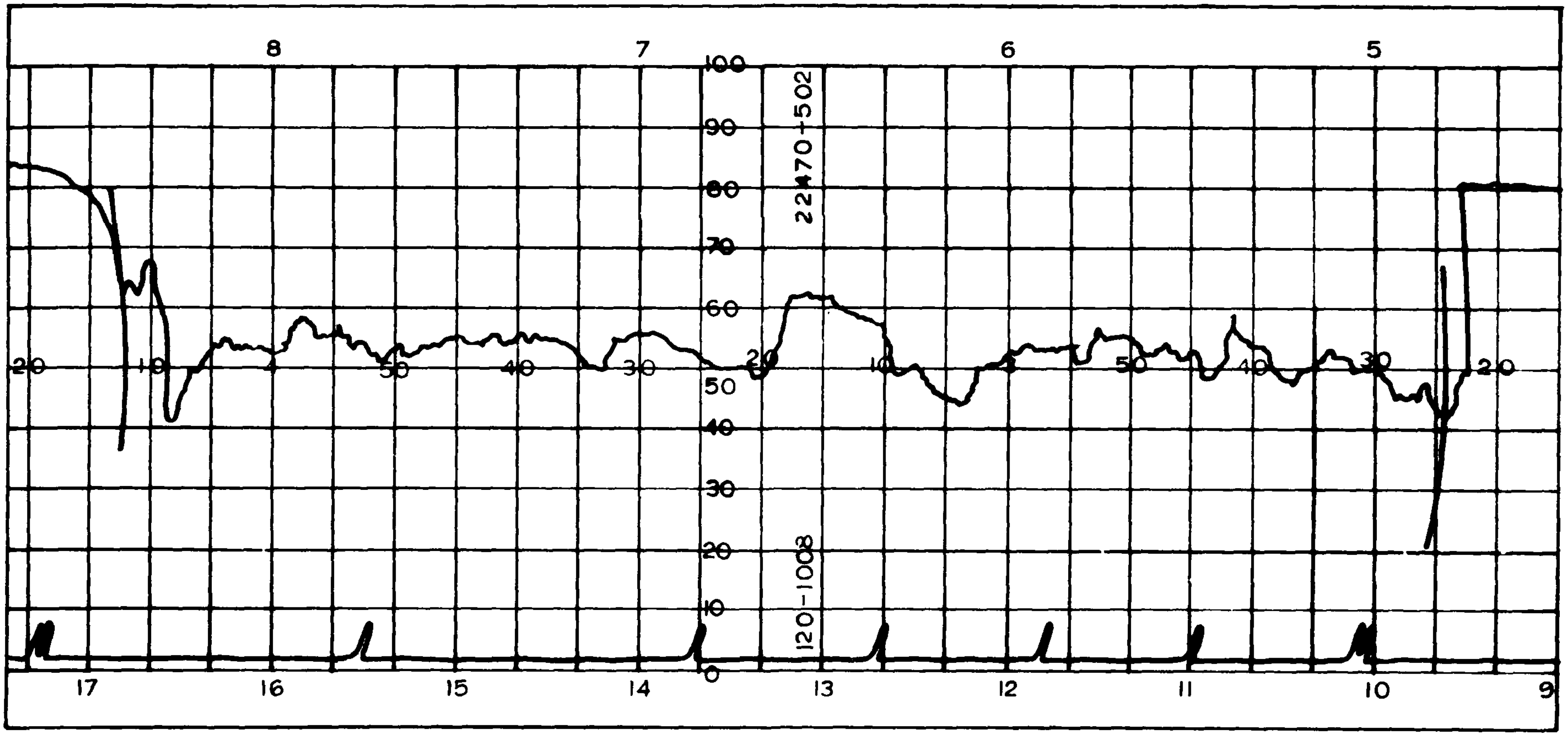
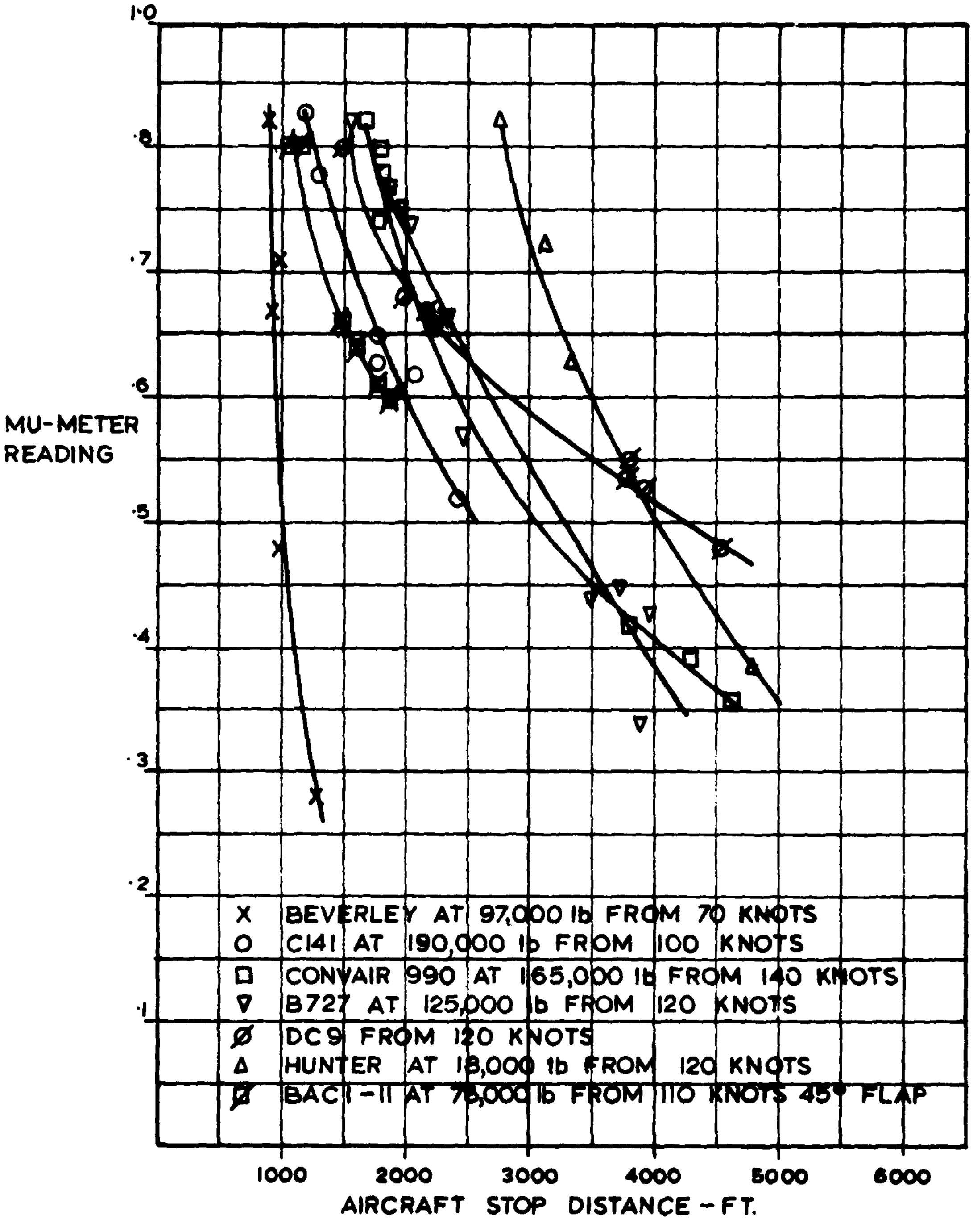


FIG. 8



RELATIONSHIP BETWEEN MU-METER READING AND STOP DISTANCES OF SOME AIRCRAFT WHICH HAVE BEEN TESTED.

FIG. 9

APPENDIX A

ANNEX B TO STANAG 3811

RUNWAY FRICTION MEASUREMENT - UK METHOD

EQUIPMENT (HIGH SPEED TRIALS)

1. A road vehicle capable of accelerating to 130 km/hour (80 mph) in 600 meters (2,000 feet) against a draw bar pull of 22.7 kg (50 lb) and with a self wetting system capable of depositing a calculated .5 mm (0.020 inches) of water over a total width of approximately 200 mm (8 inches) and length of 3050 meters (10,000 feet).

2. A Mu-Meter fitted with a means of depositing water through brushes ahead of each test wheel.

EQUIPMENT (LOW SPEED TRIALS)

3. A standard Mu-Meter at the station concerned available for use under natural rain conditions at 65 km/hour (40 mph).

A BRIEF DESCRIPTION OF THE METHOD

4. To establish both the friction characteristics and the effect of puddles forming on the runway the procedure is divided into two parts, the first (friction characteristics) being conducted at speeds up to 130 km/hour (80 mph) using equipment and personnel from a headquarters organisation, the second (formation of puddles) being carried out during periods of natural rain by Mu-Meters held by the station. The station can therefore make Mu-Meter runs under varying rainfall rates and wind directions to determine under what conditions of precipitation friction values are likely to become critical.

5. PART 1. After making the standard calibration checks, runs are made on a dry runway using the equipment in Paragraph 1 at speeds of 32 (20), 64(40), 96(60) and 130 (80) km/hour (mph) along a track approximately 5 meters from the centre line, discharging water ahead of the test wheels such that at each speed the calculated depth is approximately .5 mm (0.020 inches). The shape

of the speed/friction curve will establish whether the friction is dropping sharply but the runway is classified by the value of 130 km/hour (80 mph) in accordance with the following table.

Mu-Meter Reading Self wetting - 80 mph	Runway Friction Classification Standard	Action
6 and above	Acceptable	None
.59 to .4	Marginal	Inspect and rectify as necessary
.39 and below	Unacceptable	Corrective action required

(Note 1) There will be occasions when the average of the end to end friction value will be in the 'acceptable' category, but certain areas may give low readings due to rubber deposits or other reasons. Where these readings fall below .39 in the braking area rectification action should be taken if the contaminated area is long enough to affect stop distance in such a way as to constitute a hazard.

(Note 2) Surface friction is only one of the factors which must be considered when determining the need for remedial works to a runway. In recommending remedial action the Civil Engineer should study the Mu-Meter traces and consider such factors as runway length, transverse and longitudinal profiles, drainage characteristics, prevailing winds, surface age and condition. The final decision on whether action is taken will always rest with the operator.

6. PART 2. Details of the method to be used by the station to establish the presence and severity of puddles under natural rain conditions are given in C(G)8 - National Air Traffic Services instruction reference 8K/182/115/N45 dated 23 November 1976. Briefly it consists of runs at 40 mph down the full

length of the runway, 5 meters between each track and over its entire width. The traces and rainfall record are sent to a central agency for interpretation. Aquaplaning trials with aircraft have indicated that when a sudden drop in Mu-Meter reading to a value below 0.4 is due to a puddle, a potential aquaplaning condition exists.

7. The two parts are written up as a single report and sent to the Directorate of Flight Safety for action. This procedure is particularly applicable after an incident.

APPENDIX B

ANNEX D TO NATIONAL AIR TRAFFIC SERVICE INSTRUCTIONS TO STATIONS FOR THE PROCEDURE TO BE USED FOR A FULL WET RUNWAY EVALUATION

1. These procedures are to be used in 2 situations:

   a. Following an incident.

   b. As required by SATCO to assess any deterioration in runway conditions.

2. The Mu-Meter is at all times to be in a serviceable condition as detailed in AP 119J-1001-126A for immediate use in the event of an incident.

NB: Before commencing the evaluation the measuring wheel tyres are to be set to 10 psi $\pm \frac{1}{2}$ psi.

3. WEATHER CONDITIONS. Details to be completed on Wet Test Log.

4. PATTERN OF RUNS. Starting 2 metres left of the centreline runs are to be made at 40 mph along the full length of the runway in alternate directions in accordance with the pattern at Fig B1. It will be noted that more than one run is made at 2 metres left of centreline - this is to determine if conditions have changed.

5. Using the event bulb in the vehicle cab each run is to be identified as follows:

   2 squeezes at the start threshold

   1 squeeze as soon as 40 mph is reached

   1 squeeze before decelerating

   2 squeezes at the finish threshold

The Remote Readout Unit (RRO) is to be operated in the normal manner switched on when 40 mph is reached, change channels at each third of the runway and switched off before decelerating. In addition, the following conditions are to be observed:

   a. At regular intervals the trace is to be marked with the run number. At this point check to ensure sufficient recording roll remain to continue the operation and that the MU-METER is functioning satisfactorily.

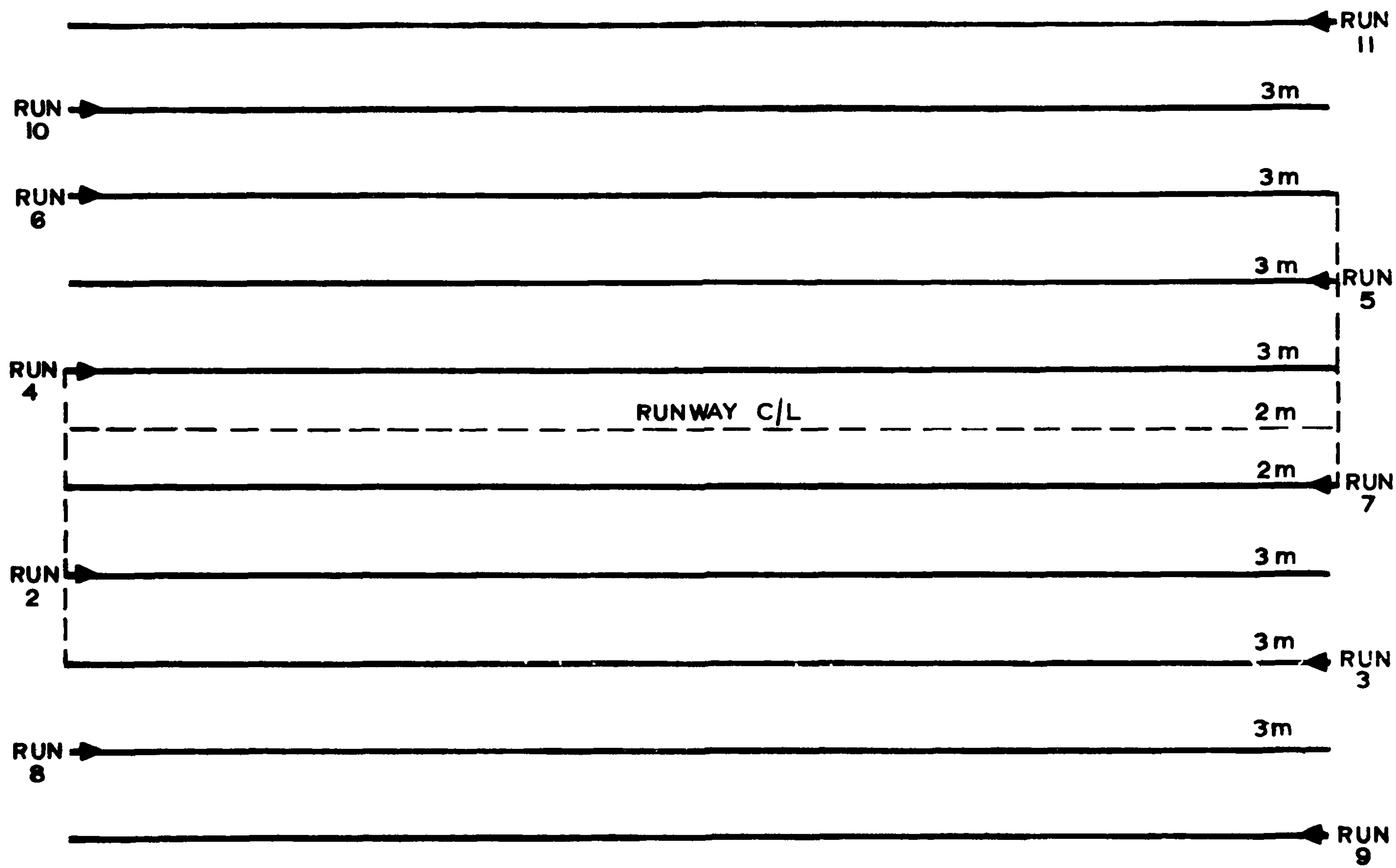
b. The test wheels are to remain splayed at all times, even if the vehicle is temporarily cleared from the runway.

c. It is essential that a wet test log is kept of all runs in the format shown - col 1 to 6 of Fig B 2.

d. At the end of the runs a copy of the rainfall trace for the day is to be obtained from the Met Office and attached to the log. If this is not available a full Rain Report for the day is to be requested.

e. To confirm the calibration of the MU-METER a run is to be made in dry conditions as soon as possible after the Wet Test runs at a position 2 metres left of centreline. The results should be recorded.

MU-METER TRACKS FOR RUNWAY CLASSIFICATION TRIAL UNDER NATURAL RAIN CONDITIONS



* RUN 1 IS RECHECKED AT RUN 7 TO ASSESS ANY CHANGES IN CONDITIONS. RUN 8 ONWARDS DEPENDS ON THE WIDTH OF RUNWAY BEING ASSESSED.

FIG. B1

G1/DW

WET TEST AND INCIDENT LOG

RAF STATION....................
DATE...........................
OPERATORS......................
....

RECORD OF LAST DRY CONDITION CHECK RUN
DATE
RRO READING (Mu)
TRACE READING (Mu)
TEST BOARD READING   DATE

TOW VEHICLE ....
REGISTRATION
RAINFALL
COMMENT
(eg Rainfall during ho[urs]
prior to test)

COL 1	COL 2	COL 3	COL 4	COL 5		COL 6									COL 7			COL 8
Run No	Dirn	Dist from C/L(M)	Time	Wind		Remote Readout									Trace			Remarks
						1	2	3	4	5	6	7	8	9				
				Dir	Velocity	C_1	B_1	C_2	B_2	C_3	B_3	Mu_1	Mu_2	Mu_3	Mu_1	Mu_2	Mu_3	

FIG B 2

APPENDIX C

RUNWAY FRICTION CLASSIFICATION OF HURN RUNWAY

IN ACCORDANCE WITH NATO STANAG 3811 ANNEX B

PART I - PROCEDURES

1. INTRODUCTION

1.1. The method of classifying runways has now been standardized by NATO in Stanag 3811 and by NATS in document 8K/182/115, the relavent parts of which are reproduced at Appendices A and B respectivly.

2. TRIALS

2.1. The trials were conducted in accordance with the documents quoted above and the results are contained in a standard format in Parts 2 and 3 of this Appendix.

APPENDIX C

RUNWAY FRICTION CLASSIFICATION OF HURN RUNWAY

PART 2 - HIGH SPEED TRIALS

1. INTRODUCTION

1.1. This note describes a runway friction classification carried out at Bournemouth (Hurn) Airport on 16 November 1977 by the Cranfield Institute of Technology.

2. RUNWAY DESCRIPTION

2.1. Fig 1 shows a schematic diagram of the runway which is 6000 ft long and 150 ft wide. The surface is of asphalt with ½" chippings. Rubber deposits at the 26 end are moderate and light at the 08 end.

3. TEST EQUIPMENT

3.1. Mu-Meter MLE 219R towed by a Ford Capri incorporating a self-wetting device capable of depositing approximately .020 inches of water beneath the Mu-Meter measuring wheels was used for the tests (Plates C(2)-1 and C(2)-2).

4. RESULTS

4.1. The results are shown in Table C(2)-1, in the standard proforma (Table C(2)-2) and in the traces of the 5 runs carried out at 80 mph (Figs C(2)-2 to C(2)-6). Further runs were made at 20, 40 and 60 mph, the results of which are shown in the speed/friction curve of Fig C(2)-7.

4.2. The average friction for the runway at 80 mph using the self-wetting equipment is .70. Rubber deposits at either end have no significant effect on the Mu-Meter reading.

5. DISCUSSION

5.1. An average reading of .70 indicates that in accordance with the standards laid down in NATO Stanag 3811, this runway is classified as 'Acceptable'. Surface texture measurements vary between .23 mm and .71 mm, and appear to be a function of the depth to which the ½" chippings have been depressed into the asphalt.

Plate C(2)-1 Mu-meter and tow vehicle

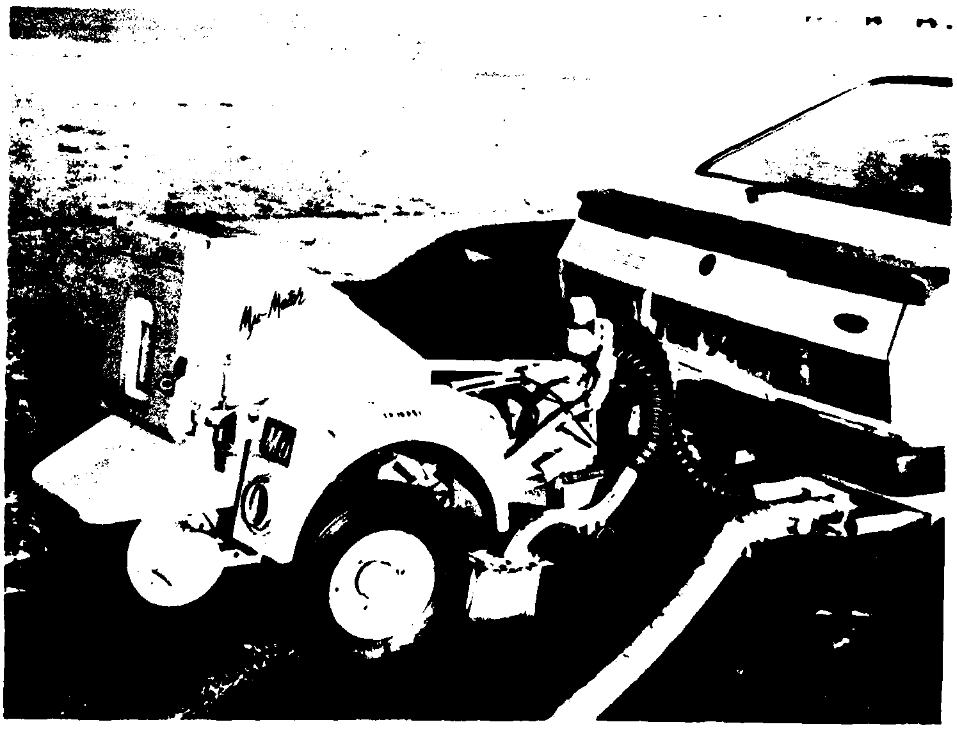


Plate C(2)-2 Self-wetting system

BOURNEMOUTH (HURN) AIRPORT

Run No	Direction	Speed mph	Self Wetting	Distance from C_L	μ_{08}	μ_c	μ_{26}
1	26	40	Off	5'S	.78	.79	.78
2	08	80	On	10'S	**	.71*	.66
3	26	80	On	15'S	.71	.72*	**
4	08	80	On	10'N	**	.71*	.66
5	26	80	On	15'N	.71	.71*	**
6	08	80	On	50'S	**	.64*	.63
7	26	20	On	5'N	.75		
8	26	40	On	5'N		.735	
9	26	60	On	5'N			.73
10	08	40	Off	5'S	.78	.77	.75

* Limited trace available for analysis-vehicle accelerating.

** No trace available-vehicle accelerating.

μ_{08} Friction reading for 1/3 of runway at 08 end.

μ_c Friction reading for 1/3 of runway centre.

μ_{26} Friction reading for 1/3 of runway at 26 end.

Table C (2)-1. DETAILS OF MU-METER RUNS ON RUNWAY 08/26

RUNWAY CLASSIFICATION PROGRAMME

Report on test at ......BOURNEMOUTH (HURN)........ Aerodrome

SECTION 1

Date of test: 16.11.77. Time: 14.00

Weather: Cloudy Wind: 15 kts. Direction: 270°

Runway direction: 08/26 Length: 6000' Width: 150'

Runway surface description: Asphalt with ½" chippings.

Runway surface condition (swept/unswept etc): Clean

Runway rubber deposits (location and approx extent) Light 08 and moderate 26 end between Vasis.

Confirm runway DRY before tests: ✓

SECTION 2

Tests conducted by: Cranfield Institute of Technology. Towing vehicle: Ford Capri

Mu-Meter calibrated on test board before beginning test. Value was:- 77

Confirm self-wetting device set at 40 galls per minute: ✓

Confirm test speed of 80 mph: ✓

SECTION 3 - Friction Measurements (Wet)

Note: Measurements to be made in both directions along tracks spaced 15 feet each side of centreline and in one direction along a track 20 feet from runway edge (middle third only).

15' South of centreline		
	Runway Hdg..08..	Reciprocal Hdg..26...
1st third	**	**
2nd third	.71*	.72
3rd third	.66	.71
Trace	2	3

15' North of centreline		
	Runway Hdg..08	Reciprocal Hdg..26...
1st third	**	**
2nd third	.71*	.71*
3rd third	.66	.71
Trace	4	5

20' from N/S edge	
	Runway Heading ...08....
Middle third	.635

Length covered by traces.

Trace No......2.. Starting at.2730..ft from t/hold r/way...08...and ending..435.ft from t/hold...26.

Trace No......3.. Starting at.3200..ft from t/hold r/way...26...and ending..574.ft from t/hold...08.

Trace No......4.. Starting at.2383.ft from t/hold r/way...08...and ending..435.ft from t/hold...26.

Trace No......5.. Starting at.3270..ft from t/hold r/way...26...and ending..539..ft from t/hold...08...

The original traces, annotated to give reasons for any significant variations in Mu-Meter values, must be attached to this form.

* SECTION 4 - Surface texture measurements (Grease patch method)

Note: One measurement for each 1000 yards of runway to be made 15' from centreline and clear of rubber deposits.

Distance from t/hold runway.......was........yds (N or S centreline) Depth =

Distance from t/hold runway.......was........yds (N or S centreline) Depth =

Distance from t/hold runway.......was........yds (N or S centreline) Depth =

SECTION 5 - Remarks:

* See Table 3.

Table C(2)-2. STANDARD PROFORMA.

Distance from 26 threshold ft.	Grease patch method mm.	Outflow Meter Secs.		
		Time 1	Time 2	Average
600	0.23	14.2	14.0	14.1
1200	0.71	3.5	2.6	3.1
2000	0.44	4.8	5.0	4.9
3200	0.41	5.5	5.0	5.3
4250	0.43	6.7	5.3	6.0
5250	0.30	8.0	11.2	9.6
Mean Value	0.42			7.2

Table C (2)-3. SURFACE TEXTURE MEASUREMENTS.

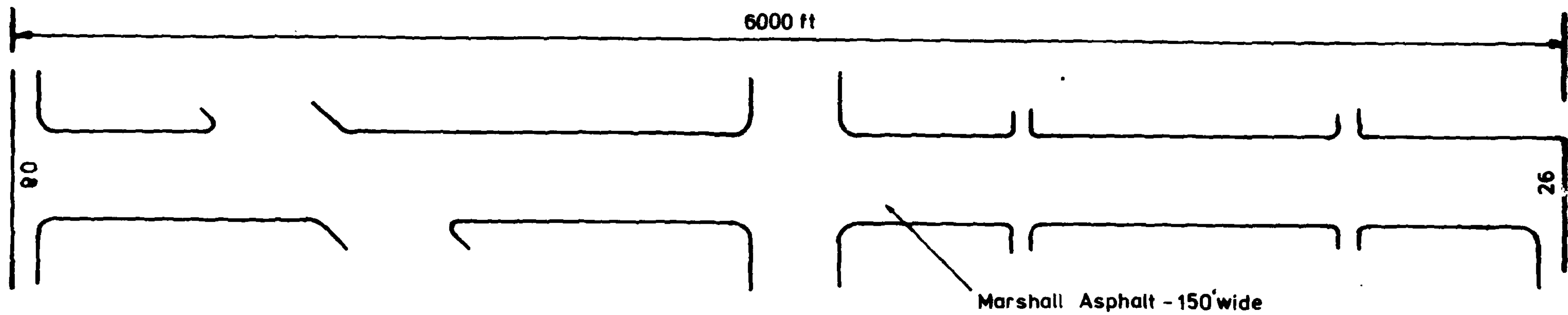


Fig C(2)-1 Schematic diagram of 08/26 runway

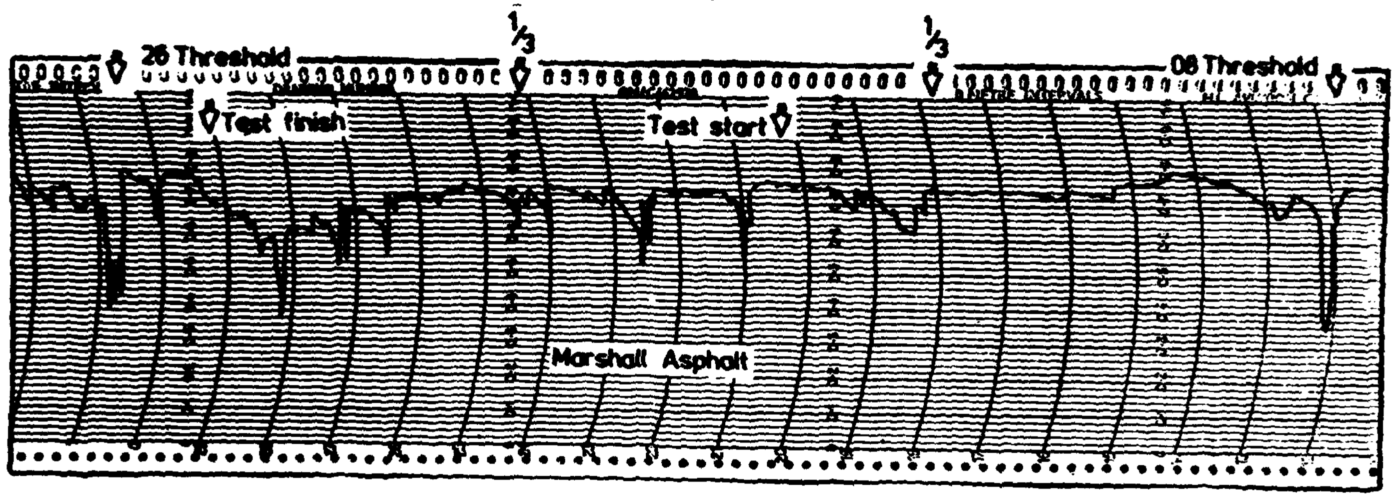


Fig C(2)-2 Run 2 Runway 08 10'S of centreline

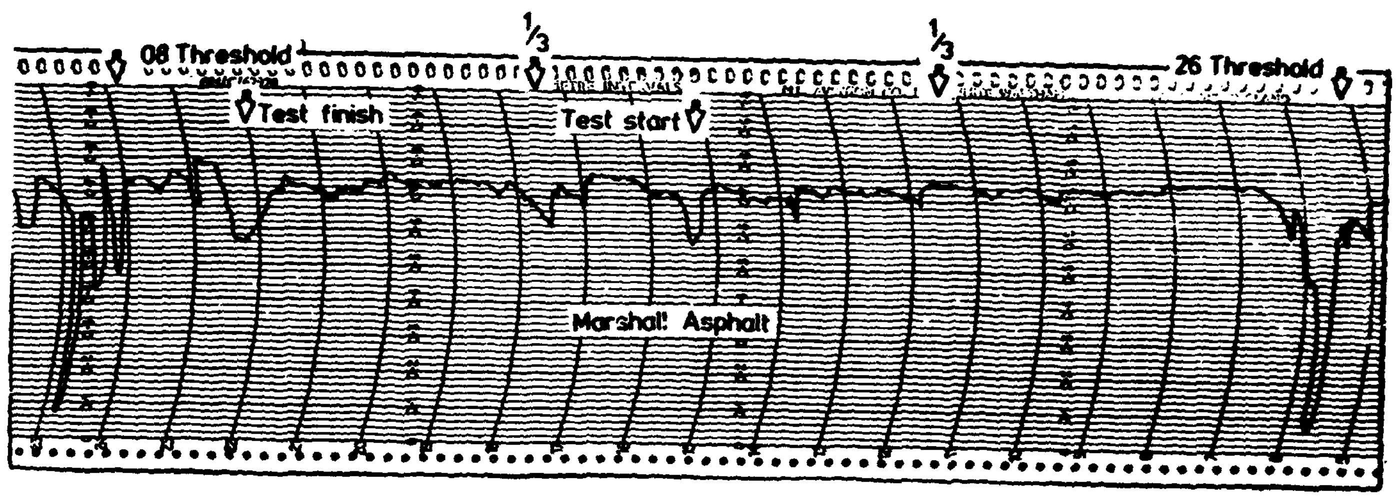


Fig C(2)-3 Run 3 Runway 26 15'S of centreline

Scale 1:2

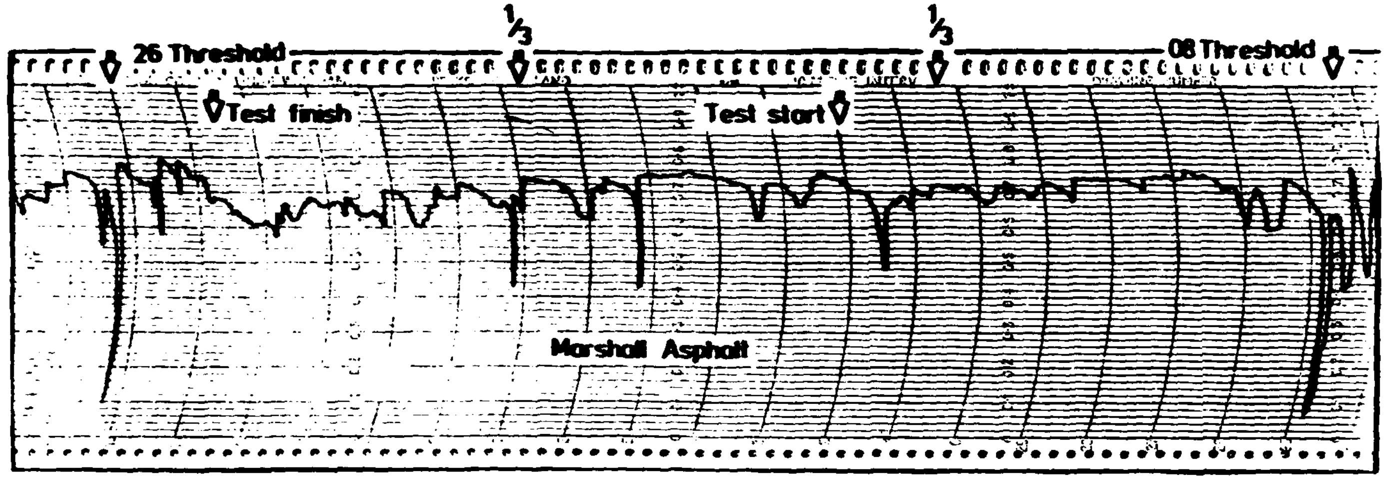


Fig C(2)-4 Run 4 Runway 08 10'N of centreline

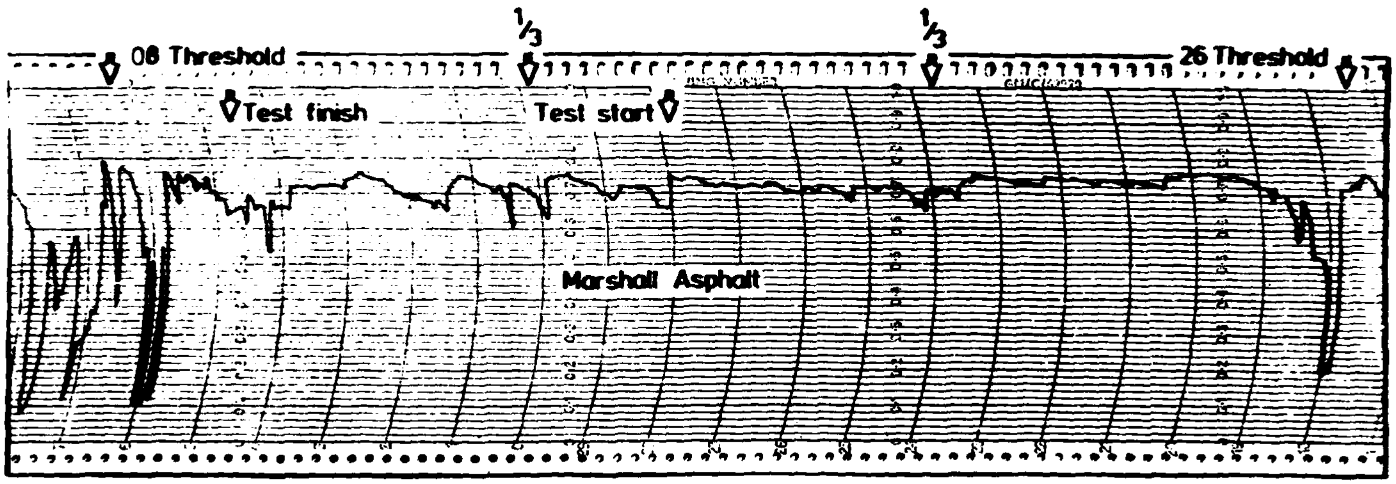


Fig C(2)-5 Run 5 Runway 26 15'N of centreline

Scale 1:2

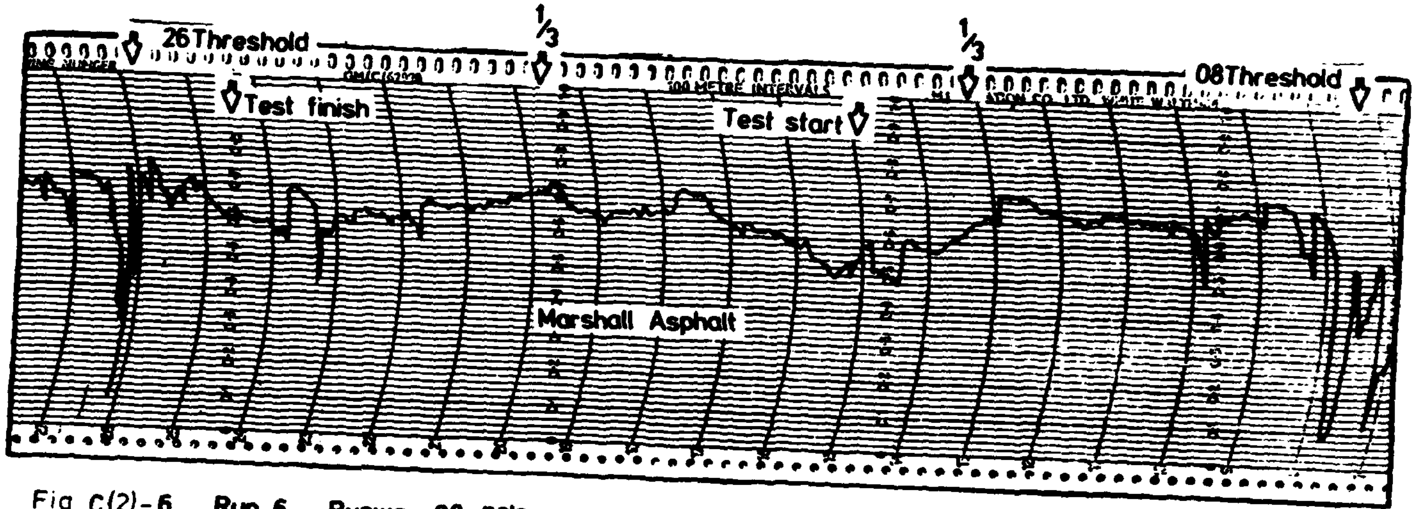
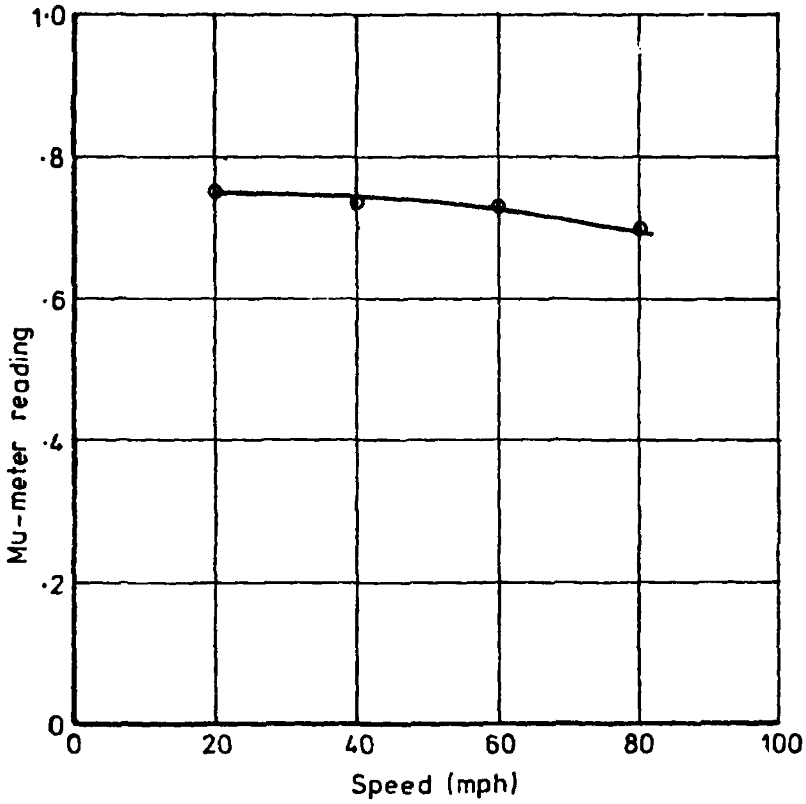


Fig C(2)-6 Run 6 Runway 08 50'S of centreline

Scale 1:2



Bournemouth (Hurn) Airport

Runway 08/26

Fig C(2)-7 Mu-meter reading v Speed

APPENDIX C

RUNWAY FRICTION CLASSIFICATION OF HURN RUNWAY

PART 3 - LOW SPEED FRICTION TRIALS

1. INTRODUCTION

1.1 Part 2 of this classification report dealt with the friction qualities of the Hurn 08/26 runway under controlled wetting conditions (constant water depth) at a Mu-Meter speed of 80 mph. Part 3 considers the friction qualities under natural rainfall conditions which, unlike Part 2, will identify any areas of low friction caused by standing water or ponding. Part 2 measured the friction within 15ft.(4.5m) of the centreline and along one edge, whilst Part 3 covers measurements over the complete width of the runway.

2. TRIALS

2.1 During the course of construction of the runway, the final surface was laid in longitudinal strips of asphalt 12ft. (3.6m) wide forming clearly identifiable lanes. Mu-Meter runs were made centrally along each of these lanes as far as the fifth lane from and either side of the centreline. Approximately every fourth run was a repeat run on the first lane south of the centreline to act as a check run. The sequence was then repeated (see Table 1).

2.2 Extra runs were made along the strip used for the aircraft braking trials described in the main report (i.e. the third lane North of the centreline). This 3600ft.test section was divided into four, using markers numbered 1-5. These marker positions were identified on the Mu-Meter traces taken over the test section during the course of the rainfall survey, enabling the friction values obtained under natural rain to be directly compared with those during artificially wetted trials conditions.

2.3 A continuously measuring rain rate gauge had been positioned close to the runway prior to the trials and, thus, the rain rate for any particular Mu-Meter run could be determined.

2.4 Figure C(3)-1 is a schematic diagram of the runway showing the 12ft (3.6m) lanes. The runway length has been divided into three to represent the thirds over which the friction reading has been averaged for each run. Superimposed are the actual results obtained along the various lanes spaced on an approximate time base. The increased frequency of check runs in the first lane south of centreline and along the aircraft test track (third lane north) can be seen. The results show that the central area of the runway (approximately 30ft (10m) either side of the centreline) has a high friction reading and that this rapidly decreases as the edge of the runway is approached but remains good (above .5 Mu-Meter reading) to approximately 50ft (15m) from the centreline. The average friction reading for each lane is indicated on Figure 1 and has been plotted against distance from centreline in Figure 3. The reason for the decrease in friction towards the runway edge is apparent when observing the surface during rain when the central area drains rapidly towards the edges where the drainage is less positive. Preliminary indications also point to a lower surface texture value at the edge of the runway. There is an area of standing water at the 08 threshold extending for approximately 300ft (91m) from the threshold and 25 ft (7.6m) south of centreline (see Figure C(3)-4).

3. RESULTS AND DISCUSSION

3.1 An expansion of the rain trace is shown in Fig.2 with the run numbers superimposed. Also on the graph are the results of the check runs (5ft south of centreline) which show the average friction reading of each third of the runway starting at the 08 end. From these can be seen the effects of rain rate on friction reading. Between zero time and 22 minutes the rate is such that the friction is dropping slowly. From 28 minutes to 48 minutes the rainrate is steady at .048"/hr (1.2mm/hr). Beyond 48 minutes the rate decreases and the friction reading rises.

3.2 A representative trace obtained along the aircraft braking trials test track during natural rainfall is illustrated in Figure C (3)-5, whilst a trace from an actual aircraft trial is shown at Figure C (3)-6. The similarity between the two traces is obvious. The initial low reading on the artificially wetted surface (Fig. C(3)-6) adjacent to marker 1 is caused by an excess of water on the surface, the bowsers having just cleared at that end.

3.3 Data from all the traces can be combined and presented as shown in Figure C(3)-7 as a friction contour map of the Hurn runway. Areas below both .5 and .4 friction reading are identified.

3.4 Run 9 (Figure C(3)-5) took place in a rain rate of .140 in/hr (3.5mm/hr) which must be considered close to the equivalent at which the aircraft runs were made during artificial (bowser) wetting.

4. CONCLUSIONS

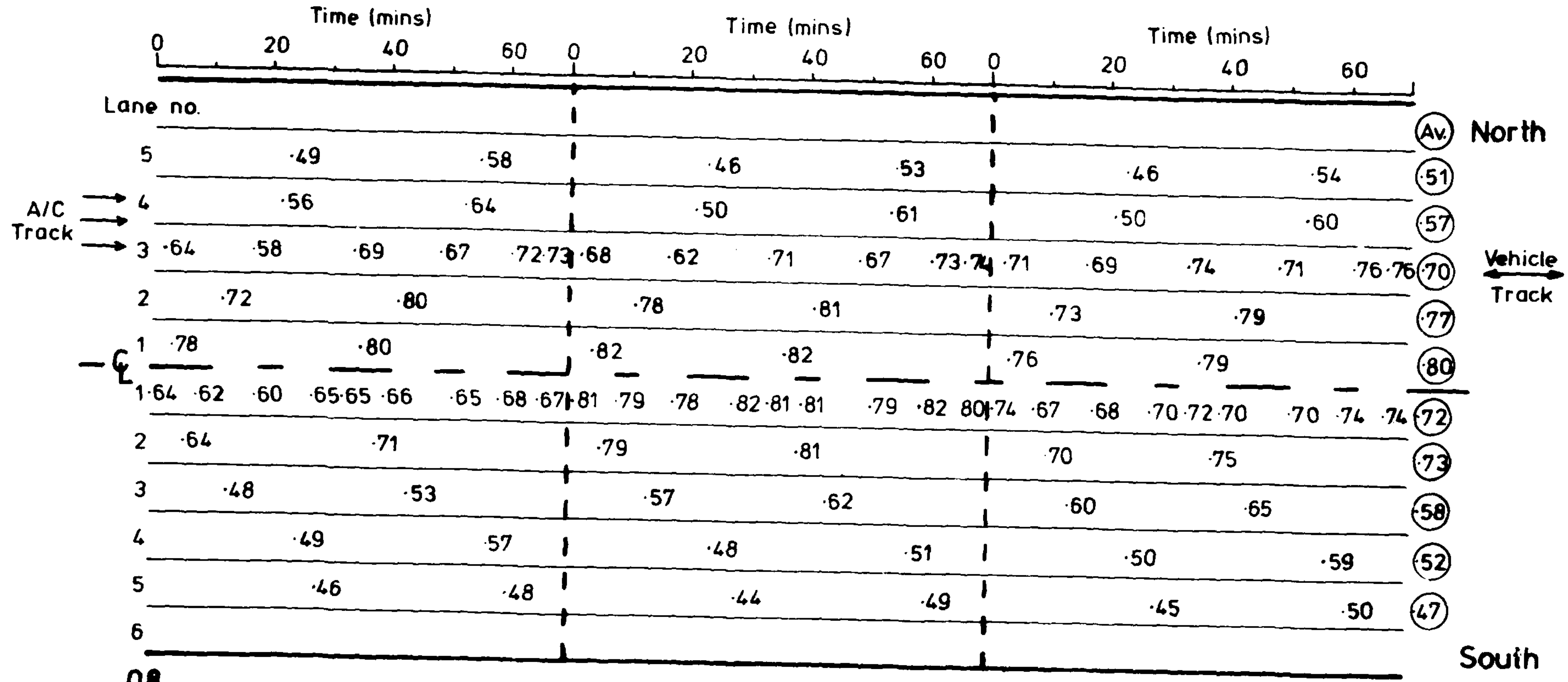
4.1. Part 2 of this Appendix has already shown that the runway 15ft (4.5m) either side of the centreline has good friction properties when tested using the standard Mu-Meter self wetting procedure. Part 3 here reported shows that the good friction area (above .5 Mu-Meter reading) under these rainfall conditins extends to approximately 50ft (15m) either side of the centreline.

4.2. Areas of low friction (below .4 Mu-Meter reading) extend along each edge of the runway, being more in evidence along the southern edge. A low friction area also occurs south of the centreline at the 08 threshold measuring approximately 25ft (7m) wide by 300ft (90m) long.

Run No.	Direction	Stop Watch Time	Lane No.	μ_{08}	μ_c	μ_{26}
1	26	0030	1st S	.64	.81	.74
2	08	0246	3rd N	.64	.68	.71
3	26	0438	1st N	.78	.82	.76
4	08	0630	2nd S	.64	.79	.70
5	26	0840	1st S	.62	.79	.67
6	08	1046	2nd N	-	-	-
7	08	1218	2nd N	.72	.78	.73
8	26	1434	3rd S	.48	.57	.60
9	08	1754	3rd N	.58	.62	.69
10	26	1944	1st S	.60	.78	.68
11	08	2210	4th N	.56	.50	.50
12	26	2414	5th N	.49	.46	.46
13	08	2616	4th S	.48	.48	.50
14	26	2816	1st S	.65	.82	.70
15	08	3016	5th S	.46	.44	.45
16	26	3246	1st S	.65	.81	.72
17	08	3436	3rd N	.69	.71	.74
18	26	3628	1st N	.80	.82	.79
19	08	3845	2nd S	.71	.81	.75
20	26	4014	1st S	.66	.81	.70
21	08	4222	2nd N	.80	.81	.79
22	26	4419	3rd S	.53	.62	.65
23	08	4947	3rd N	.67	.67	.71
24	26	5202	1st S	.65	.79	.70
25	08	5354	4th N	.64	.61	.60
26	26	5548	5th N	.58	.53	.54
27	08	5746	4th S	.57	.51	.59
28	26	5939	1st S	.68	.82	.74
29	08	6132	5th S	.48	.49	.50
30	26	6328	3rd N	.72	.73	.76
31	08	6524	3rd N	.73	.74	.76
32	26	6730	1st S	.67	.80	.74

Table C(3)-1. Details of Mu-Meter runs in natural Rainfall

t = 0 at 0909 BST.
Wind/$_V$ $180^o/_{13}$ kts.



e.g. centre third of runway, 3rd lane S, time 45mins, Mu-meter reading = ·62

Fig C(3)-1 Diagram of Hurn runway showing lanes, estimated landing track of aircraft, and actual track of friction measuring vehicles.

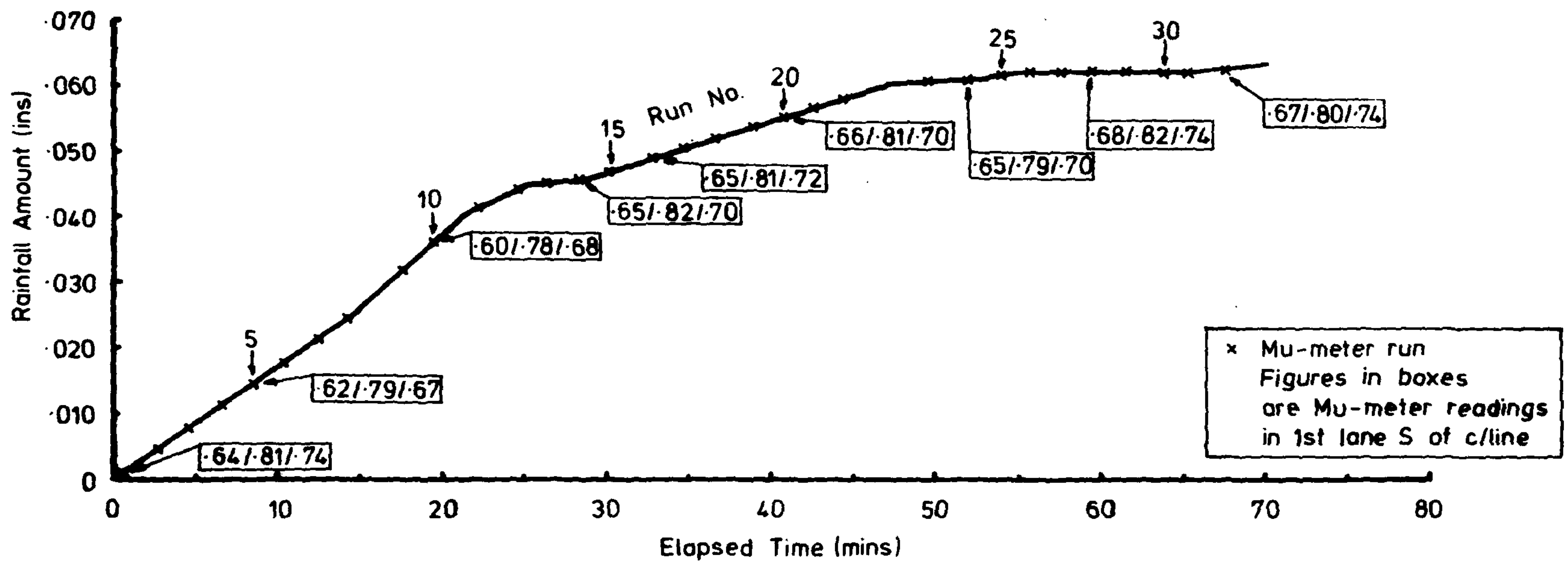


Fig C(3)-2 Mu-meter runs in rain conditions.
Rainfall rate.

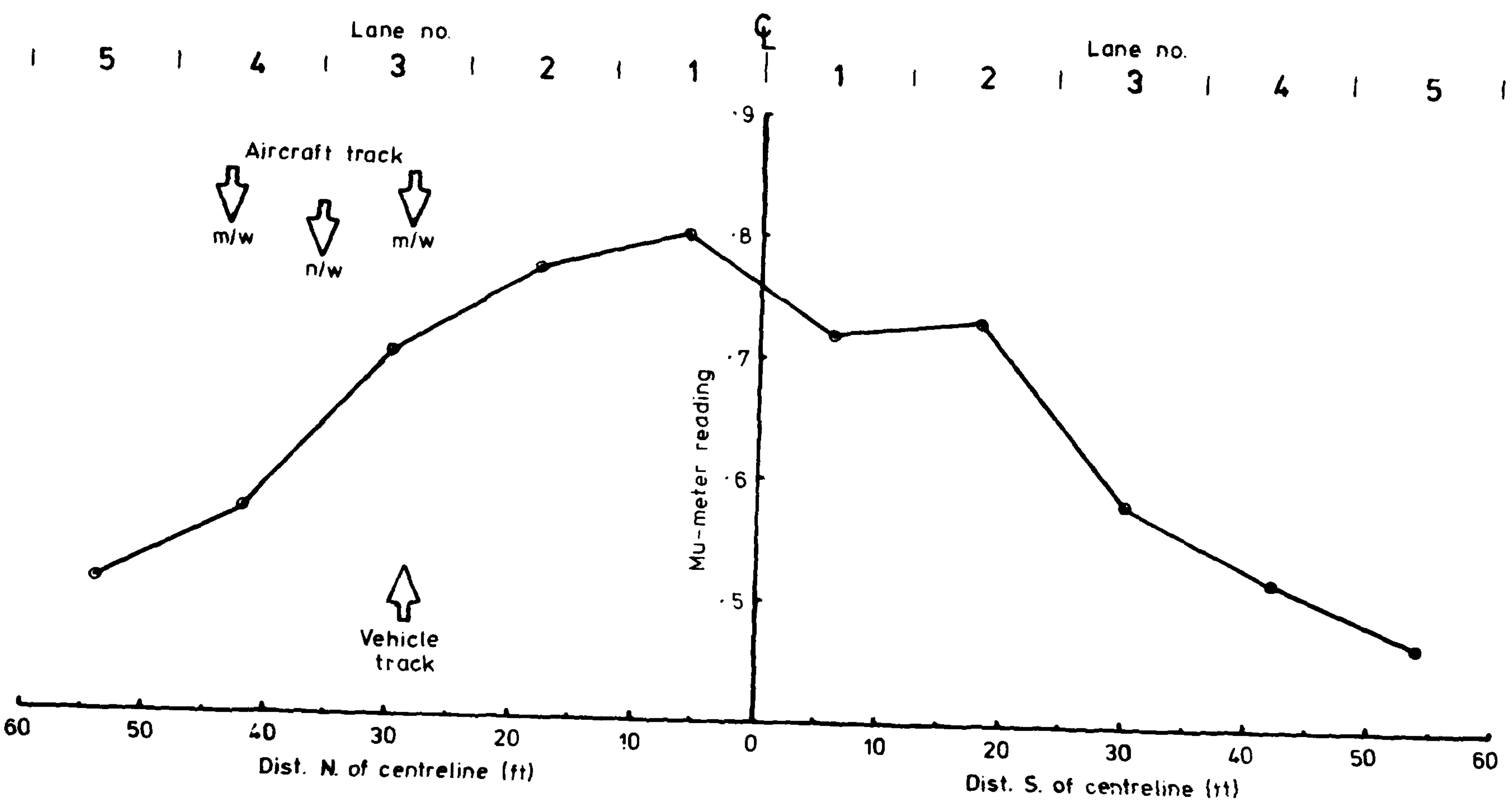
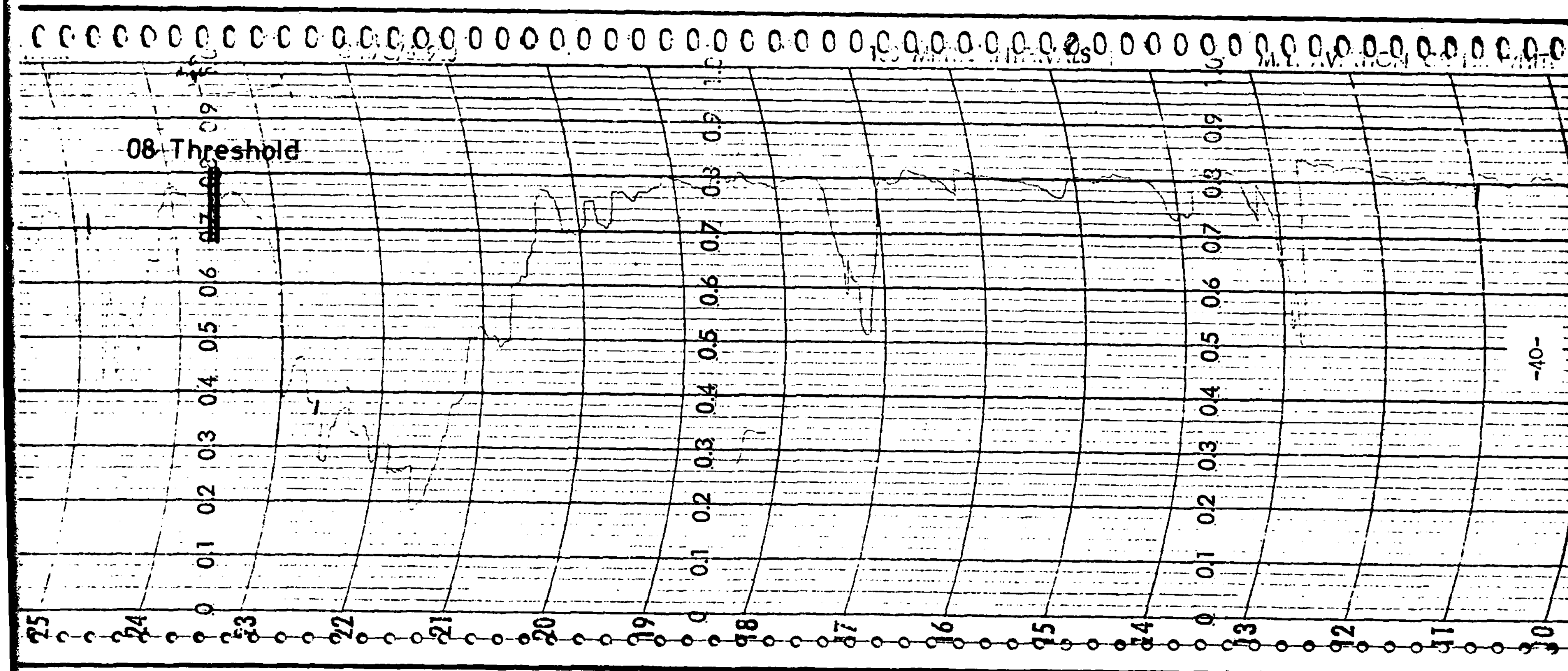


Fig C(3)-3 Average friction reading either side of centreline during rainfall.



C (3)-4 Mu-meter trace showing low friction area at 08 threshold.
Run 5 1st. lane S. of centreline.

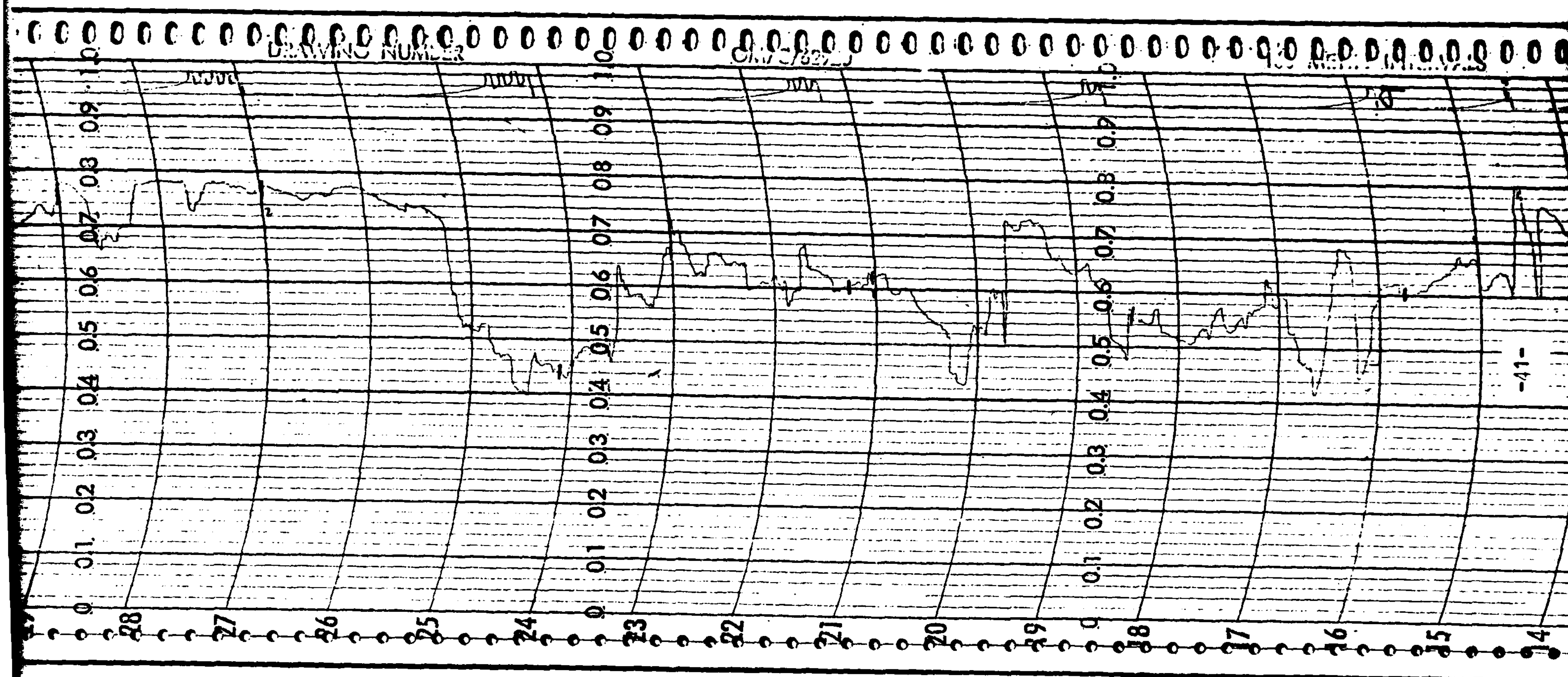


Fig C(3)-5 Mu-meter trace of braking trials test section. Natural wet.
Run 9 17·54BST 31/3/78 3rd. lane N. of centreline.

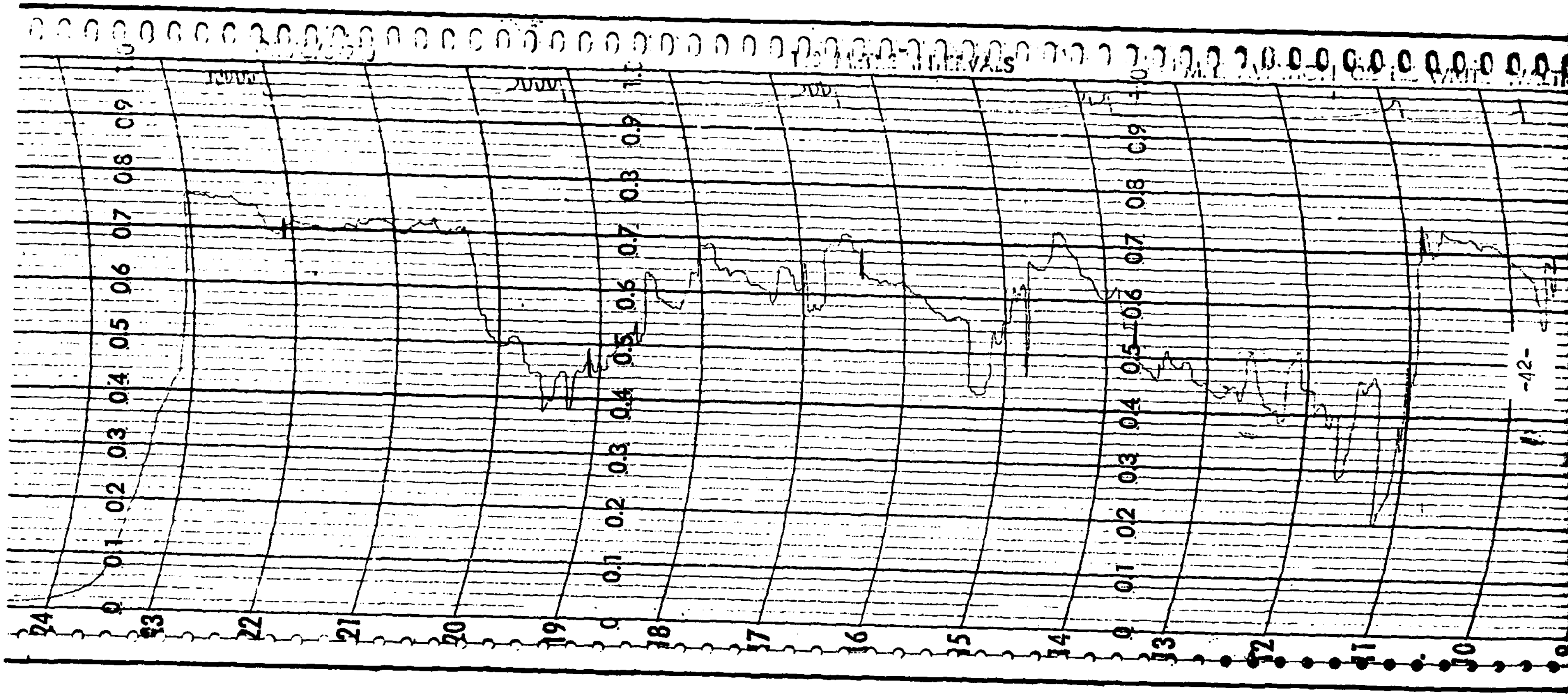


Fig C(3)-6 Mu-meter trace of braking trials test section. Artificial wet.
Run 1 18·56BST 30/3/78 3rd. lane N. of centreline.

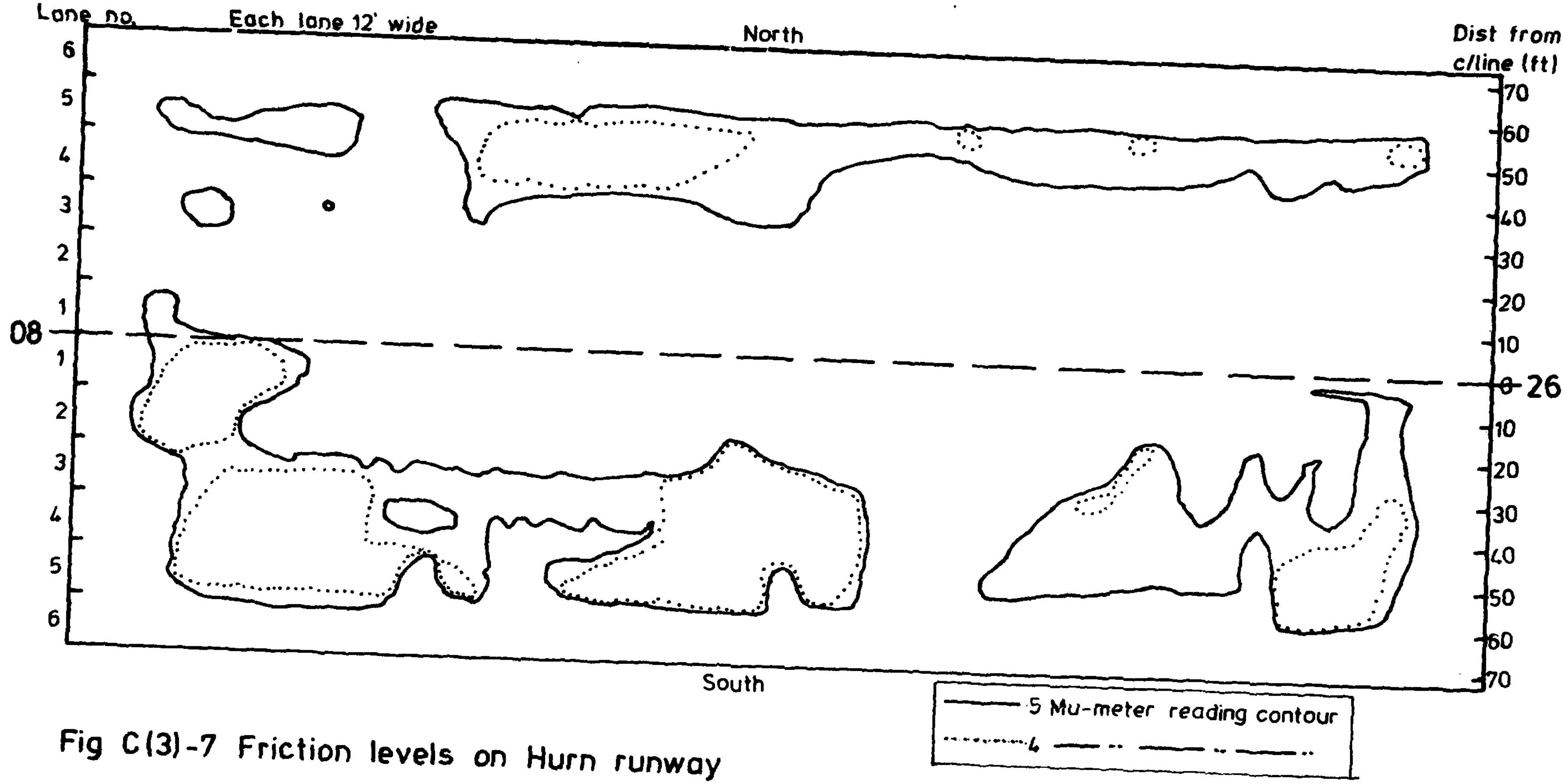


Fig C(3)-7 Friction levels on Hurn runway

APPENDIX D

A METHOD OF CONDUCTING AIRCRAFT WET BRAKING TRIALS

1. INTRODUCTION

1.1. This Appendix contains the cumulative experiences of many years testing with different types of aircraft and is presented as a guideline to those who may have to carry out aircraft wet braking trials in the future. The basic format would normally remain standard for most trials with minor variations depending on the type of aircraft being tested and the test site selected. The following are the ideal requirements for the conduct of this type of trial, but some compromise will be inevitable.

2. SELECTION OF TEST SITE

2.1. The test site is often pre-determined as the operating base of the test aircraft but if it is necessary to find another test site the following factors should be considered.

2.2. Runway Length. The minimum runway length should be determined by the summation of

a. Adequate run-in to the test section to enable the aircraft to attain a stable attitude before braking.

b. The length of test section,

c. Sufficient over-run to allow dry braking beyond the test section.

2.3. Runway Profile. Ideally the area selected for the test section should be longitudinally as flat as possible. A runway with a single cross fall is preferable to one with a camber since the water flow of the former is across the test section and not away from it as with the latter.

2.4. Runway Approach. In order to comply with para 2.2. a. the aircraft approach path should be clear of obstacles so that the touch-down can be near to the threshold.

2.5. Conflicting Traffic. Airfields which also operate commercial traffic should be avoided unless the trial aircraft can be given absolute priority over other traffic.

2.6 Water Supplies. There should be sufficient water to allow for the refilling of four 2,500 bowsers in a period of approximately 20 minutes.

2.7 Runway Surface Friction. The required friction value should be considered in the planning stages, having regard to the fact that Ref 1 recommends a Mu-Meter reading of 0.55 ±.05, and that a Runway Friction Classification should be carried out. The classification at Hurn has been described in Appendix C Parts 2 and 3 but briefly runs are made along the runway with a Mu-Meter at both high and low speeds. The high speed runs are made at 80 mph using a self wetting device to make sure the amount of water beneath the friction measuring wheels is constant and a known standard which can be reproduced on other surfaces so that a strict comparison can be made (See Ref 2 Fig 11).

2.8 The slow speed tests should be performed during constant moderate to heavy rainfall. The Mu-Meter is towed at 40 mph making several runs to cover the full width of the runway. The friction values obtained are related to the rainfall rate and any areas of ponding can be identified by fluctations in friction.

3. TEST SEQUENCE

3.1 Aircraft. The aircraft should aim to take off before the bowsers commence wetting if a single runway only is in use. If an alternative runway is available then take-off can be at the pilot's discretion. If the lowest friction value is to be attained the landing must be made immediately the bowsers and Mu-Meter have cleared the runway. To this end, strict timing must be maintained by the trials controller who should inform the pilot at regular intervals when the runway will be clear. After landing, the aircraft must clear the test section immediately to allow the Mu-Meter to make its second run. It may sometimes be possible for the aircraft to clear to the edge of the runway allowing the Mu-Meter to continue to make its runs whilst the aircraft taxis to dispersal.

3.2. It is anticipated that many of the aircraft runs will be performed at the lowest friction value possible. But when the requirement is for tests to be carried out at intermediate friction values, then measurements must be taken at intervals with the Mu-Meter until the required value is approached, at which time the aircraft can be asked to land. Some idea of the time to reach the required value can be obtained by studying previous drying curves for the test section, eg Fig 4. If an alternative runway is available, then the aircraft take-off may be delayed until the required time approaches, otherwise the aircraft must remain airborne until instructed to land.

3.3. Bowsers. It is difficult to achieve an evenly wetted test section if the bowsers all travel in the same direction, as water laid at the start will have mostly drained away by the time the bowsers reach the end of the section. Their formation must depend largely on the number available and cross fall of the runway. The wetting procedure at Hurn, where 4 bowsers were used has been explained in the main part of this report. Fig D1 shows suggested bowser formations depending on runway profile.

3.4. It may be necessary to supplement the bowser wetting with fast moving fire vehicles depositing more water along the test section without disrupting the normal timing sequence. Once the bowsers have finished wetting they must refill immediately if further trials are planned.

3.5. The question of whether to wet the runway twice before the aircraft braked run has been examined in more detail in Appendix E but, briefly, it appears to make no difference to the friction values obtained during a trial.

3.6. Friction Measurement. The slipperiness of the runway is measured by the Mu-Meter and previous trials show that it is essential for the operators to be experienced in its use when operating with an aircraft. To determine the friction value of the runway at the precise time of the aircraft landing, it is necessary to carry out measurements before and after the landing on a strict time basis. By extrapolating between them the value at aircraft landing time can be determined.

More than one measurement after the landing should be made so that a Mu-Meter reading versus time graph (drying out curve) can be established accurately.

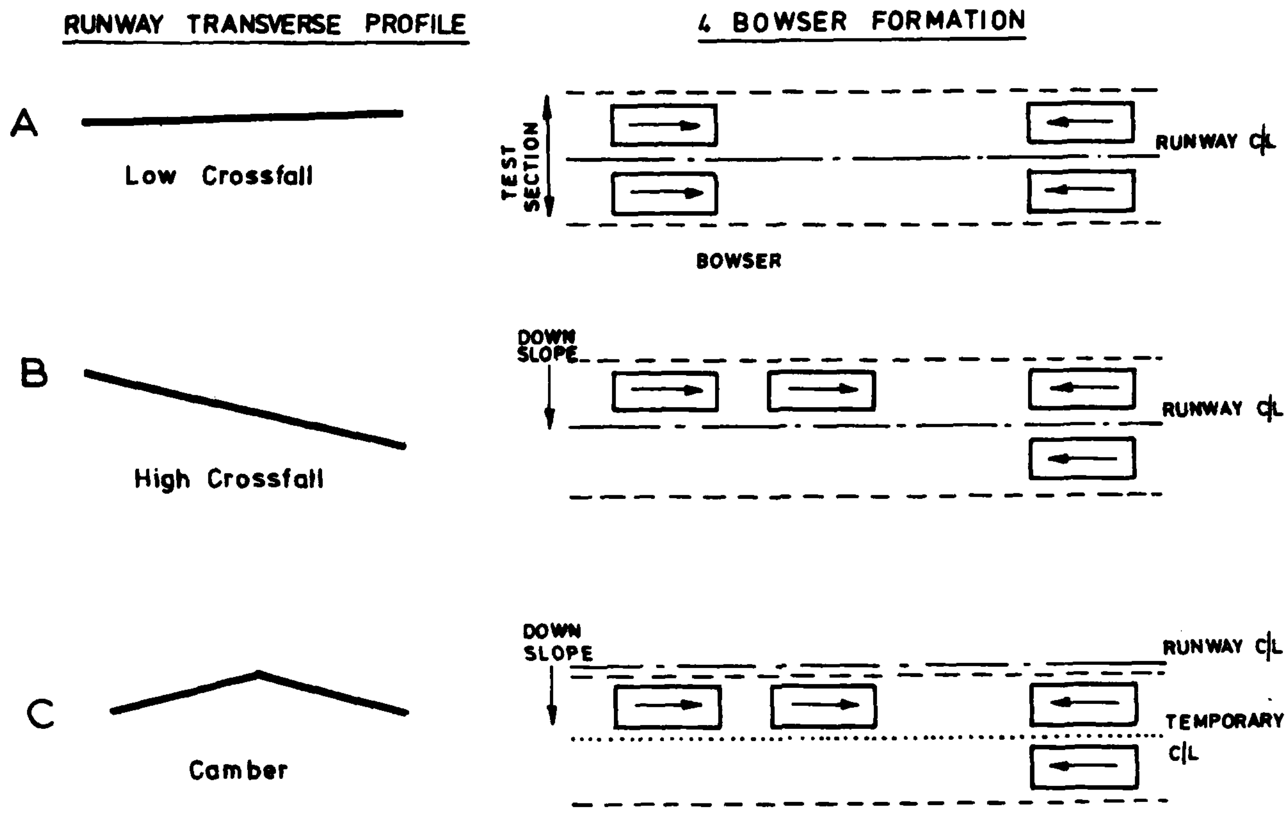
3.7. It is essential that each run is made along the same track, preferably that of the aircraft nose wheel. Failure to do this can result in erronious readings. If the test section is displaced from the centre-line of the runway, the friction measuring (and aircraft) track must be marked by some means, ie a temporary centre-line or some natural line feature, (concrete pans or asphalt-laying strips) which must be followed. It may be interesting to determine the friction values along other tracks in the test section but this should be carried out during pre-wetting or in specially arranged trials without the aircraft. The relationship between the friction along different tracks will be established in any case during the runway classification (see Appendix C, Part 3).

3.8. <u>Water Depth Measurements</u>. If measurements of water depths are required, experience has shown that to have any confidence in the results it is essential to obtain a reasonable number of measurements along the entire test section. Measurements should be made simultaneously at points not more than 500ft apart and on exactly the same spot. There are at least 3 different types of water depth gauges but for the sake of uniformity the one developed by the Cranfield Institute of Technology is used as a standard in the United Kingdom.

3.9. <u>Surface Texture Measurement</u>. One of the conclusions of Ref 2 is that measuring surface texture by the grease patch or Outflow Meter methods do not provide a sufficiently definitive measure of runway friction to warrant its use.

4. <u>COMMUNICATIONS</u>

4.1. Where possible the trials controller should be positioned in the Air Traffic Control in order to have an overall view of the proceedings and also to be in direct contact with the aircraft and other activities on the runway eg bowsers. An emergency system eg flashing runway lights or an Aldis lamp, should be arranged in case of communications failure.



N.B. Bowser formation as in B, test section displaced to one side of runway centre line.

These formations will give 30' wide test section using 15' spray bars as fitted to MOD (PE) water bowsers.

FIG. D1 SUGGESTED BOWSER FORMATIONS FOR MAXIMUM RUNWAY WETNESS

APPENDIX E

TO INVESTIGATE THE ADVANTAGE OF WETTING A RUNWAY TWICE TO INCREASE ITS WETNESS PRIOR TO AIRCRAFT BRAKING TRIALS

1. INTRODUCTION

1.1 Some authorities recommend that in order to reduce the friction values on a runway to a minimum the runway should be wetted twice before the aircraft braking run. The technique involves wetting the runway some time prior to the actual trial (1st wetting), using either the bowsers or fire vehicles, then refilling and wetting the test area again (2nd wetting) immediately before the aircraft braking run. The advantages of this technique are considered in this Appendix based on data obtained in the BAC 1-11 trials at Hurn.

2. TRIALS AND RESULTS

2.1 On four occasions at Hurn, Mu-Meter runs were made during a double wetting sequence. The results are shown in Table E1 and Figure E1. The Mu-Meter readings in the Table are arranged in four pairs; the first figure in each pair is the Mu-Meter reading immediately after the 1st wetting and the second is that immediately after the 2nd wetting. It can be seen that on only one occasion is the reading after the second wetting lower than after the first. In order to eliminate any variation due to timing, the readings have been plotted against time after the completion of wetting (Fig E1). The graph shows that there is no significant difference in the friction level when a runway is wetted either once or twice.

3. CONCLUSION

3.1 Evidence gathered during the BAC 1-11 trials at Hurn indicates that with a minimum gap between wettings of 34 minutes there is no advantage in wetting the runway twice prior to an aircraft trial in order to make the runway more slippery.

Mu-Meter Run No	Average Mu-Meter Reading	Time after end of wetting (secs.)		Time Between 1st & 2nd Wetting - Mins
		1st Wetting	2nd Wetting	
71 73	.52 .55	30	44	34
85 87	.46 .57	60	84	34
108 114	.54 .56	30	64	35
120 124	.58 .54	127	85	39

TABLE E1 Details of Mu-Meter readings during a double wetting sequence.

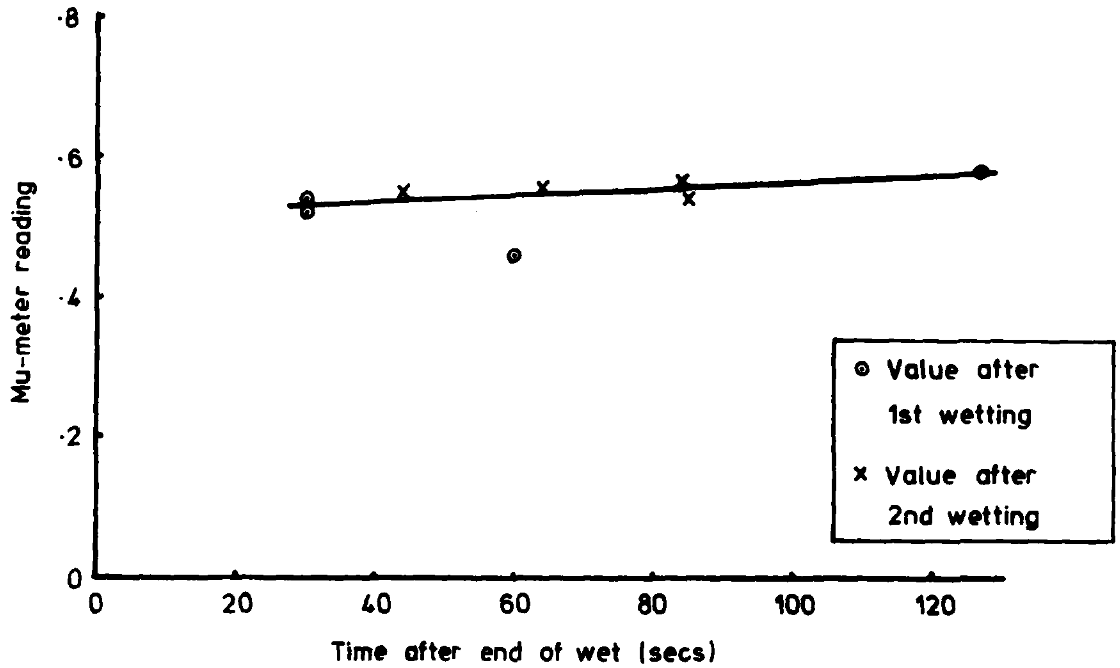


Fig E1 Effect of double wetting on Mu-meter reading

APPENDIX F

DETERMINING THE MU-METER SPEED/FRICTION CURVE FOR THE HURN RUNWAY TEST AREA

1. OBJECTIVE

1.1 When using the method described in para 3 of Ref.1 to correct aircraft stop distances to the Standard Military Reference Wet Curve it is first necessary to obtain the Mu-Meter speed/friction curve for the surface under the condition used for the aircraft trial. Ref. 1 describes two methods which can be used depending on facilities and time available. The first method is the least accurate since to predict the curve it relies on an already established relationship between the 40 mph Mu-Meter reading and those at 60, 80 and 100 mph. Inevitably this method can introduce some errors since it assumes the runway being used for the trial will conform to those already tested. This Appendix describes how the second and more accurate method was used at Hurn.

2. TRIALS

2.1 Because of the time required on the runway, these trials were conducted separately from the aircraft during either trial wettings or after the first wetting of a two wetting sequence before the aircraft braked landing. The method was to make runs at 20, 40, 60 and 80 mph recording the time of each run and to continue until the Mu-Meter reading at 40 mph reached .7.

3. RESULTS AND DISCUSSION

3.1 Fig F1 shows the Mu-Meter readings plotted at various speeds against time. As only one result was available at 80 mph an estimated line has been drawn for this speed based on the obvious trend.

3.2 As expected the speed/friction curve obtained by plotting readings at the same point in time altered as the runway dried out. Mu-Meter readings at 40 mph of .55 and .6 have been chosen to give an example of this and to show how the curves can be extrapolated beyond the maximum test speed of 80 mph.

3.3 By using the standard form of equation recommended in Ref. 1 and data points from Fig F1, the best fit equation for this runway at a 40 mph Mu-Meter reading of .6 is

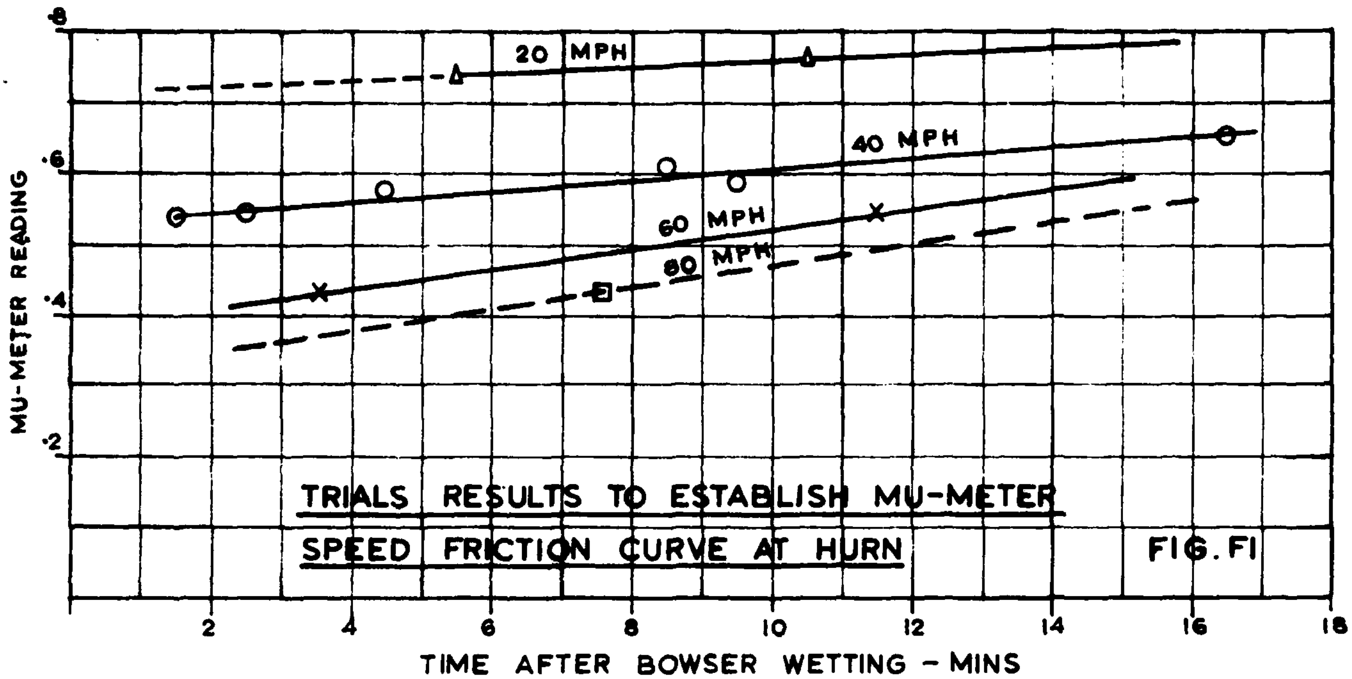
$$\mu_V = .23 + 10^{-\frac{V + 30}{167}}$$

and for .55 is

$$\mu_V = .20 + 10^{-\frac{V + 13}{117}}$$

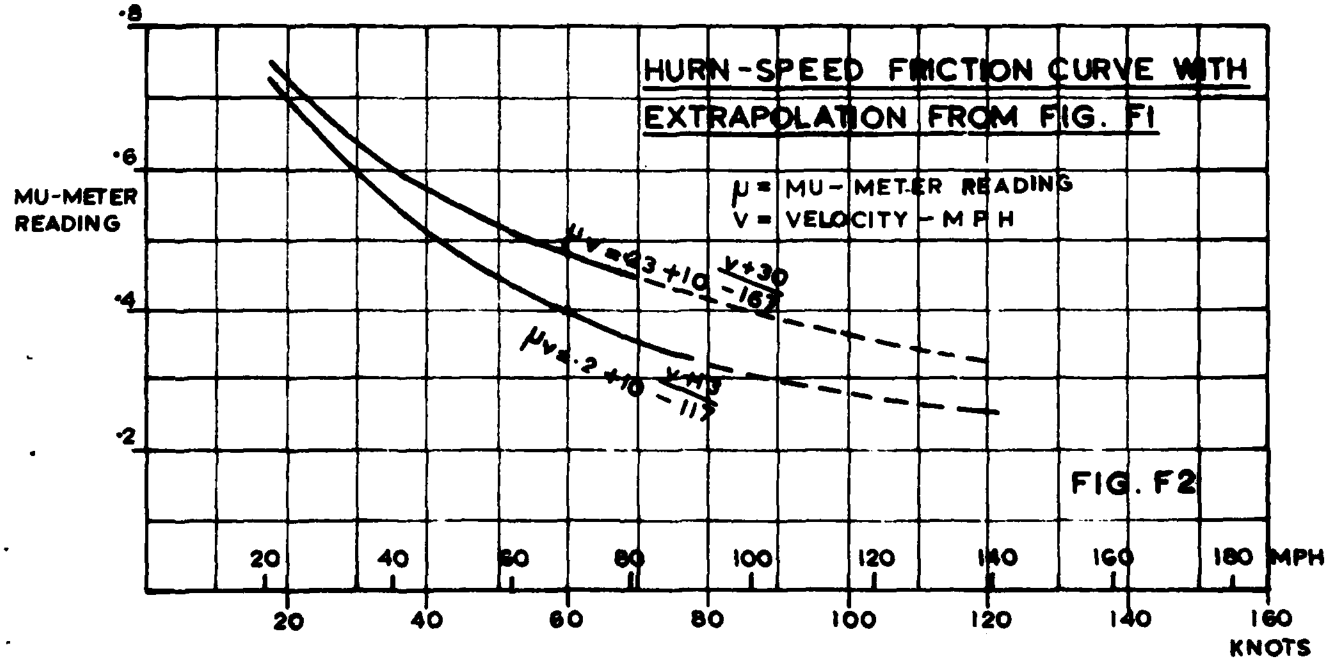
where μ_V is the Mu-Meter reading at velocity V in mph.

The curves for these equations are plotted in Fig F2 for speeds up to 140 mph.



TRIALS RESULTS TO ESTABLISH MU-METER SPEED FRICTION CURVE AT HURN

FIG. F1



HURN-SPEED FRICTION CURVE WITH EXTRAPOLATION FROM FIG. F1

FIG. F2

APPENDIX G

G - HAWK WET RUNWAY TRIALS

1. INTRODUCTION

1.1 The need to conduct wet runway braking trials on G Hawk to clear a modified brake provided the second opportunity to determine an aircraft stop distance on the Standard Military Reference Wet Surface as a further check of the practicality of the method and test procedure.

2. AIRCRAFT

2.1 The aircraft was standard except that the brakes had been modified to provide a larger heat sink.

2.2 Deceleration was measured by an F47 camera situated at the side of the runway whilst longitudinal deceleration, pitch angle, brake pressures and main wheel speeds were recorded on aircraft instrumentation.

3. TEST SECTION

3.1 Tests were carried out on the Dunsfold runway which is 6000 ft long and 150 ft wide surfaced with a worn slurry seal. A practise wetting with the water bowsers produced extensive puddling along the whole test section which was confirmed by large fluctuations in the Mu-Meter trace, see Fig G-1. However the trace did indicate that an average friction condition could be produced which was within the limits that Ref 1 recommended could be corrected to the Standard Military Reference Wet friction/speed curve. The calculation of the average friction along the test area would have been easier had the trace been similar to those in Figs 3, 4 and 8.

4. RUNWAY WETTING

4.1 The four 2500 gallon bowsers used at Hurn were also used for this trial, however as the Dunsfold runway had a crossfall, the test track was down the centre line and the appropriate bowser formation recommended in Appendix D, was used.

5. AIRCRAFT TRIALS

5.1 Figs G2 and G3 show the Mu-Meter reading/time plots for the 3 wet aircraft runs. By allowing a gap of approximately 20 minutes for the water to drain away between runs 1 and 2, it was possible to test under both wet and damp conditions.

5.2 Fig G4 shows the relationship between Mu-Meter reading and aircraft stop distance from 105 knots in zero wind at a weight of approximately 8850 lb.

6. DISCUSSION

6.1 Although the Mu-Meter trace for the Dunsfold runway showed wide fluctuations with friction due to the presence of puddles a close study showed the average for the very wet runs to be close to the .55 which defines the Standard Military Reference Wet Surface. In the case of this aircraft deceleration had to be used in place of friction coefficient to determine the 'standard' stop distance. This would normally have reduced the accuracy of the result and to compensate it was decided that the Ref 1 method could still be used provided the Mu-Meter reading at the time of the aircraft run was within $.55 \pm .03$ instead of $\pm .05$ when friction coefficient is used. As both of the very wet runs were within this limit, Run 1 was chosen to be corrected.

6.2 The shape of the Mu-Meter reading/aircraft stop distance curve is unusual when compared with those for other aircraft, see Fig 9.
It would appear that the slightest amount of moisture on the surface, causes the stop distance to increase by about 75%. However as this depends on a single result it should be treated with reserve until confirmed.

6.3 The wide and frequent fluctuations in friction along the runway may have degraded the performance of the anti-skid system.

7. CONCLUSIONS

7.1. At an aircraft weight of approximately 8850 lb, the stop distance from 105 knots on the Standard Military Reference Wet Surface is 3240 ft.

7.2. The aircraft stop distance appears to increase dispeoportionately under damp conditions.

MU-METER TRACE FOR DUNSFOLD

AFTER BOWSER WETTING – SLURRY SURFACE

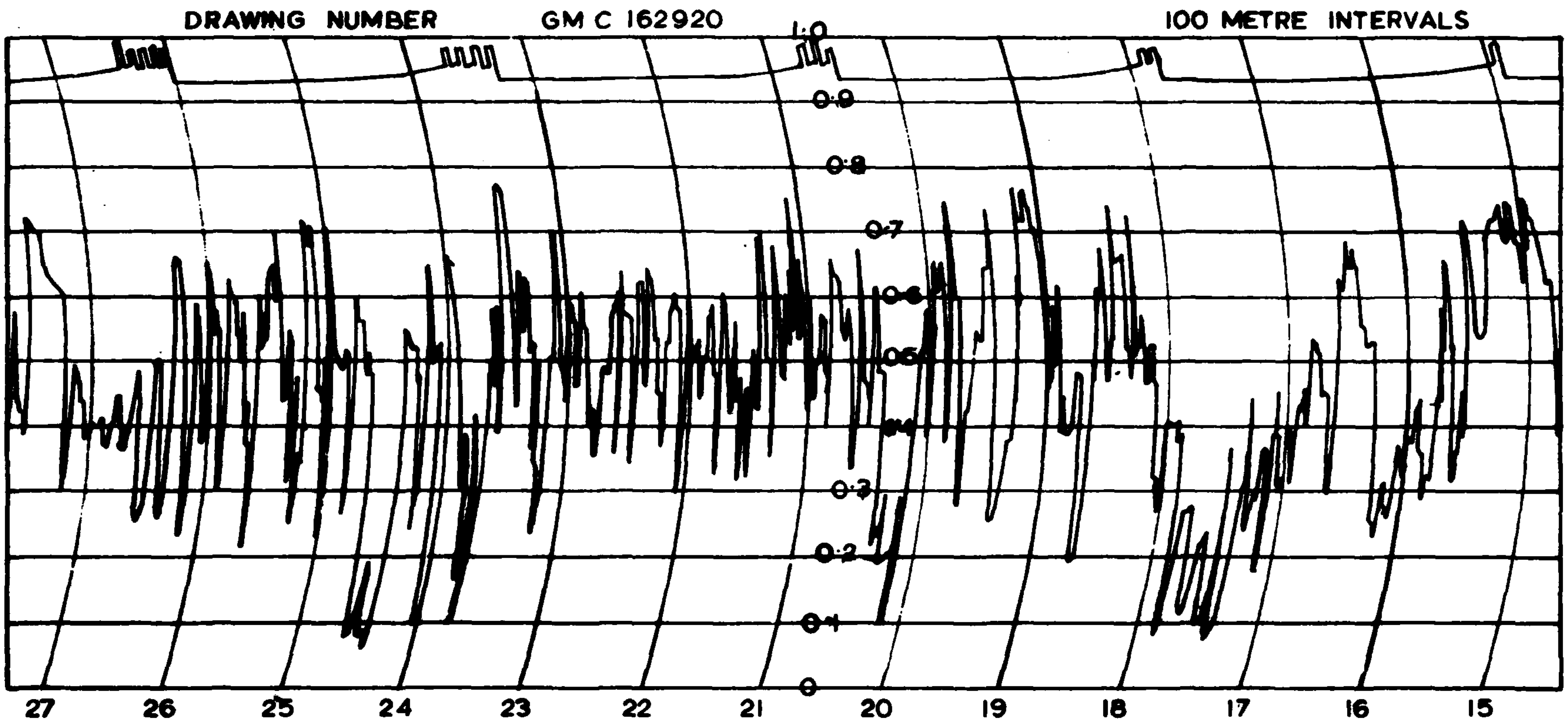


FIG. 1

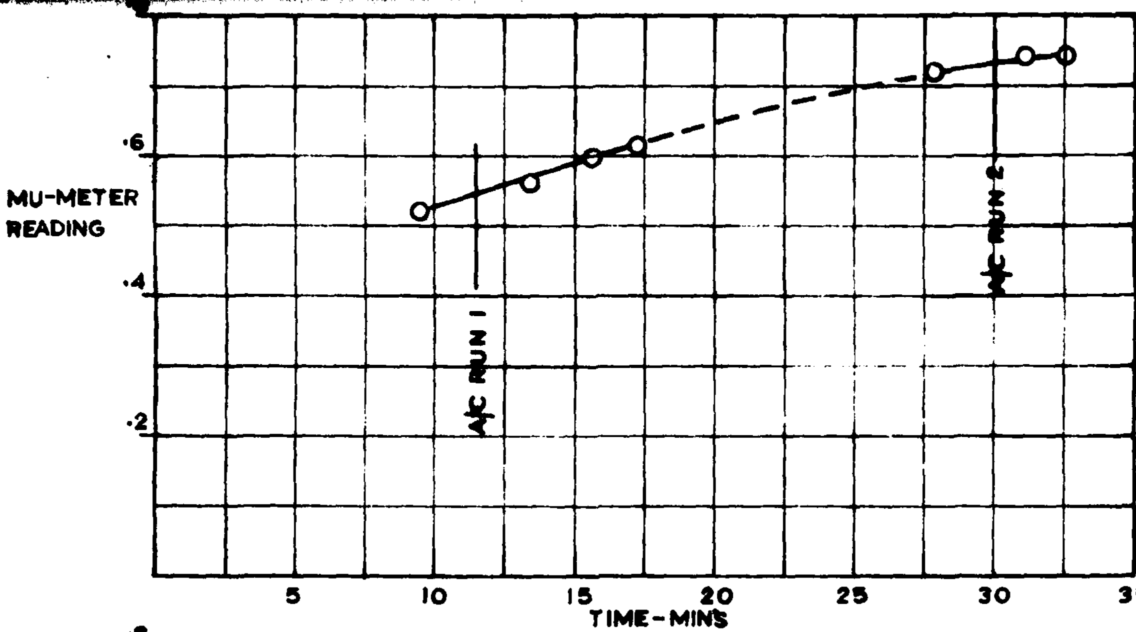


FIG.G2

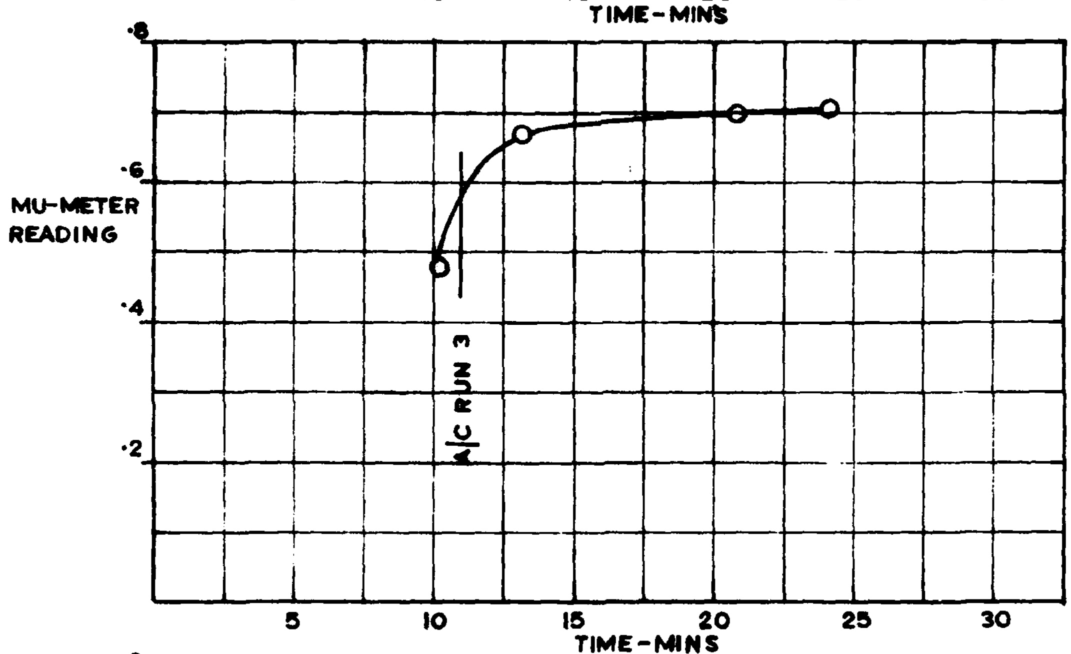


FIG.G3

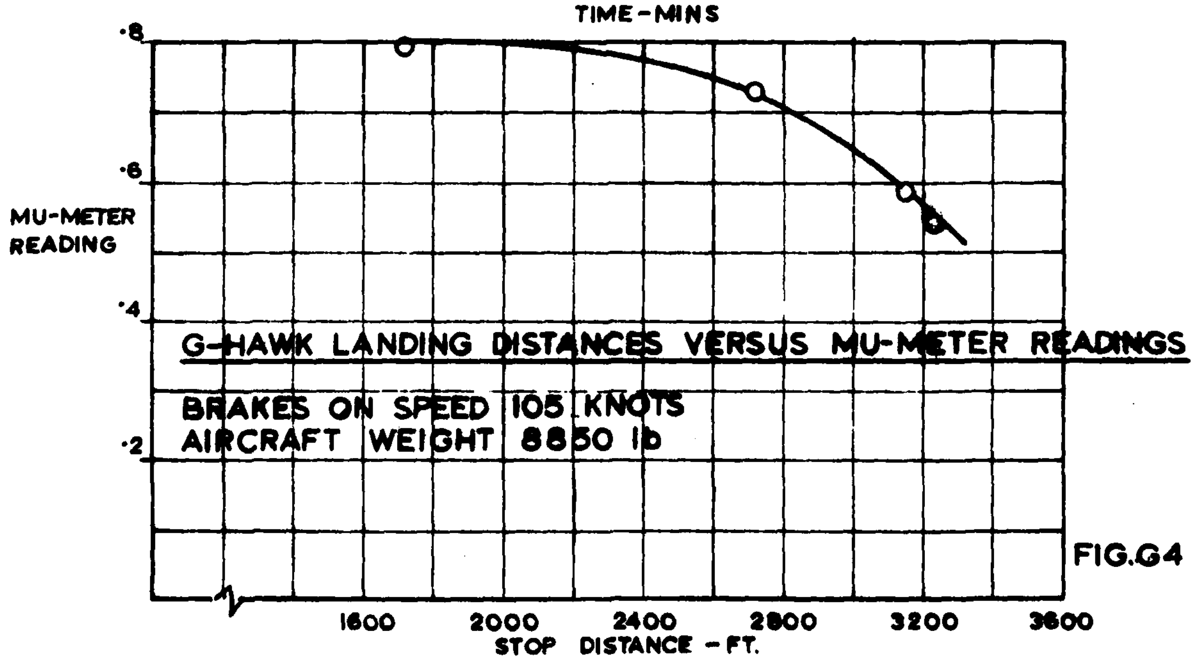


FIG.G4

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8. Author 1. Surname, initials	9a Author 2	9b Authors 3, 4...	10. Date	pp	ref
Beaty, I.	Sugg, R.W.		10.1979	64	2

11. Contract Number	12. Period	13. Project	14. Other References

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Descriptors (or keywords)

*Aircraft landing, *Friction, *Runways, *Skid resistance, *Surface waters, BAC-1-11 (aircraft), Braking, Distance, Moisture content, Performance tests, Stopping, Surface properties.

Abstract The main part of this report is concerned with a trial to determine if there was any difference in the stop distance of a BAC 1-11 aircraft under wet runway conditions when fitted with three different modern anti-skid systems. The test runway was wetted by four water bowsers and the slipperyness of the surface at the time of the aircraft braked runs determined by a Mu-Meter friction trailer. A test with the Mu-Meter during a period of natural rain confirmed the similarity in runway friction between natural and bowser wetting methods. By comparing the aircraft stop distances at the Mu-Meter reading of .6 it was concluded that although the two more modern systems appeared to give the shorter distance, the difference was small and based on insufficient data points to give a high degree of confidence. The aircraft Braking Force Coefficient versus speed and Mu-Meter reading from one of the runs has been used to demonstrate the use of the method recommended in Ref 1 to determine the

over

DRIC/76/27

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stop distance on the Standard Military Reference Wet Surface at the weight at which the aircraft was tested. The Appendices contain a method of deciding on the suitability of a test runway for aircraft/Mu-Meter braking trials using National and NATO standards, recommendations on how to conduct the trials and how to determine Mu-Meter speed/friction curves for the test surface. A brief description is given of a trial on a runway with a large amount of standing water.